Spatial Designs for Sustainable Oil Palm Expansion in Riau Province – Indonesia

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by

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Abstract

The increasing unsustainable expansion of oil palm has drawn much attention globally. Although the main actors in the oil palm sector have recognized the importance of managing oil palm plantations sustainably, there is still much to be done. Comprehensive studies and realistic plans for accommodating projected expansion, investing wisely in further expansion and protecting sensitive land from invasion by new oil palm plantations is needed. To support the decision makers in solving this problem, critical studies like this and high-quality data sets are required. Riau province, compared to other provinces in Indonesia, has the highest number of oil palm plantations. This has led to undesired expansion of oil palm into areas that are not suitable or which are very important for conservation. Proper spatial planning of land use is likely the key strategy in reducing the pressure on land. This study actually targeted national and local governments who are responsible for spatial planning. Producers and NGOs are not and do not have decision power. They can only lobby and try to convince the government of their point of view. It is against this background that this study aimed at supporting the government. In this study I assessed the opinions of oil palm stakeholders on where expansion would be possible in the most environmentally sustainable way. The main aim of this research was to develop a scientifically sound decision support tool for determining suitable land for sustainable oil palm expansion, based on the views of oil palm stakeholders. The general approach of the study involved the integration of GIS and spatial multi criteria evaluation techniques. First, a general survey was carried out to identify the relevant criteria for oil palm site selection, value functions developed for each criterion, and then suitability maps created for each vision. Later, all suitability maps created for each vision were aggregated with the land cover map with potential land units for oil palm conversion (grassland, cleared areas, burnt areas, acacia and rubber plantations etc). Finally, I analyzed suitability values and ranked areas based on these values. A decision support tool was developed which can be updated anytime new data is availed. This tool enables transparent communication between oil palm stakeholders on which areas can potentially be used for further oil palm expansion. Available spatial data were used to produce suitability maps for each stakeholder group using spatial multi criteria evaluation within the ILWIS software. Standardization and weighting of relevant criteria, was based on information from interviewed stakeholders and on expert views. Alternative sites were then defined and assessed for the final result. The results showed how stakeholder opinions on environmental criteria can be translated into spatial data layers on land suitability for oil palm. This will facilitate communication between stakeholders because it is a transparent and objective way of developing expansion scenarios. However, these results do not reflect a final ranking of areas based on suitability. Further updating and improving of the spatial data layers is necessary before this spatial decision support tool can be used. Positional accuracy and unavailability of data could contribute to the accuracy of the results. Recommendation for further research is given in order to develop an effective decision support system for sustainable oil palm site selection in Riau province.

Key words: Oil palm, spatial planning, value functions, stakeholders, suitability, ranking, Riau.

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List of Acronyms

SMCE: Spatial Multi Criteria Evaluation
GIS: Geo Information Systems
FAO: Food and Agricultural Organization
HCVF: High Conservation Value Forests
RSPO: Roundtable on Sustainable Palm Oil
SDSS: Spatial Decision Support Systems
MCDM: Multi Criteria Decision Methods
ILWIS: The Integrated Land and Water Information System
MCDA: Multi-Criteria Decision Analysis
DSS: Decision support System
TGHK: Tata Guna Hutan Kesepakatan
CBIS: Computer-Based Information System
WWF: World Wildlife Fund
CPO: Crude Palm Oil
PKO: Palm Kernel Oil
SPSS: Statistical Package for Social Sciences
DEM: Digital Elevation Model
NGO: Non Government Organization

Glossary

Land evaluation: "The process of assessment of the performance of land when used for specified purposes, involving the execution and interpretation of surveys and studies of landforms, soils, land use vegetation, climate and other aspects of land in order to identify and make a comparison of promising land use types in terms applicable to the objectives of the evaluation" (FAO, 1989).

Sustainable land use: "Land use guaranteeing continuity productivity of land without severe or permanent deterioration in the resources of the land" (FAO, 1989).

Value functions: "Mathematical representation of human judgments" (Beinat, 1997).

Spatial Decision Support System*:* "An interactive, flexible and adaptable Computer-Based Information System (CBIS) especially developed for supporting the solution of a particular management problem for decision making" (Turban, 1995).

Data base: "A structured (non-redundant) set of data whereby the data can be shared for different uses (questions)", (FAO, 1989).

High Conservation Value Forests (HCVFs): According to Forest Stewardship Council HCVFs are forests of outstanding and critical importance due to their high environmental, socio-economic, biodiversity or, landscape values.

Attributes: An attribute is the means or information sources available to the decision maker for formulating and achieving the decision maker's objectives (Starr and Zeleny, 1977).

1. Introduction

Palm oil is one of the world's leading agricultural commodities. According to (Carrere, 2001), oil palm (*Elaeis guineensis*) originated from West Africa. However, it is currently grown in all tropical, low-lying and high-rainfall areas (Carrere, 2001). The conditions necessary for the growth of oil palm include; minimum temperature of 18°C, humid tropical lowland climate with the mean of 2000 mm or more and evenly distributed rainfall throughout the year (Moll, 1987; Sharma, 2009). The palm grows well in disturbed forests and near rivers but does not yield well under closed canopies (Corley and Tinker, 2003; Sharma, 2009). The palm is also tolerant of a wide range of soil types, as long as water is available (Mantel. et al., 2007; NewCROP, 1996).

The main product derived from the fruits is crude palm oil (CPO) which is mainly used as cooking oil and as a resource in the food industry (Casson, 2003; Van Gelder and Bloemen, 2004). But it has also several other applications e.g. in the cosmetic, leather and textile, metal and chemical industries (Basiron, 2007). Lately, palm oil has also received much attention as a potential source for biofuel production (Lam et al., 2009; Royal Society, 2008). Another product, palm kernel oil (PKO), which is derived after crushing the palm kernel, is also used in the food industry as well as in the production of soaps, detergents and cosmetics (Murphy, 2007). Compared to other major oil crops, oil palm also has lower production costs and produces more oil from less land (Hansen, 2007; Sheil et al., 2009) check table 1).

Table 1:Oil production of palm and other major oil crops
Source: Cited in (Sheil et al., 2009)

Oil type	Oil yield (kg/ha)
Palm†	4000–5000
Rapeseed†	1000
Groundnut†	890
Sunflower†	800
Soya bean†	375
Coconut‡	395
Cotton seed‡	173
Sesame seed‡	159

The present area under oil palm is approximately 14 Mha (FAOSTAT, 2009) of which around 80 percent is found in Malaysia and Indonesia (Koh and Wilcove, 2007). The demand for palm oil is still expected to increase (Corley, 2009) but on the other hand, serious concerns about unregulated oil palm expansion increased too (Fitzherbert et al., 2008; Royal Society, 2008; Van Gelder and Wakker, 2006).

Increasing concerns on unsustainable production of palm oil among the public, Non Government Organizations (NGOs) and consumers led to the formation of the "Roundtable on Sustainable Palm Oil (RSPO)" on 8th April 2004. RSPO members and participants in its activities come from different backgrounds. They include: oil palm producers, palm oil processors or traders, consumer goods manufacturers, retailers, banks and investors, environmental or nature conservation NGOs and social or developmental NGOs (RSPO, 2009). The governance structure of RSPO aims at fair representation of all stakeholders throughout the entire supply chain but end users, policy makers and government authorities are not directly represented (van Duren et al., 2010). This implies that whatever is decided within the RSPO has no legal binding status (van Duren et al., 2010). The global multi-stakeholders platform has 8 defined principles and 39 criteria accompanied by indicators to be used in monitoring and sustainable certification for palm oil production (for details refer to (RSPO, 2009). Some of these criteria and indicators address an environmental issue, such as principles 4, 5, and 7, which stresses the use of best practices, conservation of natural resources and biodiversity and lastly responsible development of new plantings.

Environmental impact assessment is nowadays frequently part of the procedure in expanding plantations or establishing new ones (RSPO, 2007). However, although some oil plantations are well managed, others have imposed social and environmental costs (Ardiansyah, 2006). WWF Indonesia (Ardiansyah, 2006) reported that conversion of High Conservation Value Forests (HCVF) caused habitat loss and habitat fragmentation for many species. According to (Casson, 2003), spatial data and other evidence suggest that oil palm plantations have been developed within a number of national park buffer zones (including Tanjung Puting National Park, Bukit Tiga Puluh National Park, Gunung Leuser National Park and Danau Sentarum National Park) and other forest areas of high conservation values. In Indonesia and Malaysia, over 50% of the palm oil plantations established between 1990 and 2005 were created at the expense of natural forests, (Koh and Wilcove, 2008), yet expansion of oil palm to marginal lands increases investment and production costs and affects sustainability (Mantel. et al., 2007). It also resulted in increased numbers of human–wildlife conflicts (Ardiansyah, 2006).

According to (Mantel. et al., 2007), since the early 1980s, the total amount of land allocated to mature oil palm has more than tripled globally. “Most of this expansion has occurred in Indonesia, where the total land area of oil palm plantations increased by over 2100 per cent over the same period, growing to 4.6 million hectares”(FAOSTAT, 2009). “Most production comes from Sumatra, but is expanding rapidly in Kalimantan and spreading further east to Papua” (Sheil et al., 2009). In Indonesia (Erwidodo and Astana, 2004; Sharma, 2009), Sumatra has the majority of existing oil palm plantations, located mainly in four provinces: North Sumatra, Riau, South Sumatra and Jambi. However, the expansion was the highest in Riau amongst all the provinces in Indonesia (Casson, 2003; Sharma, 2009). Riau province lost over 65% of its forest cover in the last 25 years from 1982 – 2007,(Sharma, 2009; WWF, 2008a). Out of the forest cover lost, 29% was cleared for industrial oil palm plantations, 7.2% by the smallholder oil palm plantations, 24% was cleared for industrial pulpwood plantations, and 17% became so called “waste” land (land that was deforested but not replaced by any crop cover, (WWF, 2008a). Riau has almost 1,195,178 hectares of these “waste” lands (WWF, 2007) where plantations could potentially be developed without converting more natural forests.

This intensive expansion proves that the procedures for environmental impact assessment, land use planning, and proper process for development of concessions are neglected hence need for a spatial planning policy. It also proves that, determining the impacts and looking at ways of mitigating them alone, may not be the most effective strategy. Proper spatial planning of oil palm expansions will contribute more efficiently to environmental protection because it may achieve the same objective of increased production while avoiding negative impacts. Incorporating spatial planning in redirecting plantation development to suitable areas would facilitate the development of the oil palm sector while avoiding environmental problems (Mantel. et al., 2007). “There is now little doubt that unregulated oil palm expansion poses a serious threat to tropical ecosystems, biodiversity and potentially the global climate (Fitzherbert et al., 2008; Koh et al., 2009; Koh and Wilcove, 2007, 2008); current research ought to focus on developing mitigation strategies”(Koh et al., 2009).

Recently, three land management approaches for reducing the detrimental impacts of agriculture on biodiversity have been proposed: land sparing, which seeks to minimize land requirements by maximizing yields on intensively farmed lands, wildlife-friendly farming, which aims at enhancing biodiversity within agricultural landscapes (Fischer et al., 2008; Green et al., 2005; Koh et al., 2009; Matson and Vitousek, 2006) and a third approach: which seeks to design landscapes threatened by biofuel (oil palm or other) expansion in recognition of biodiversity, economic and livelihood needs. In this study, a fourth approach was proposed: Decision Support System (DSS) for sustainable oil palm site selection using stakeholder views.

A DSS is an interactive, flexible and adaptable Computer-Based Information System (CBIS), especially developed for supporting the solution of a particular management problem for decision making (Turban, 1995). Most of the information required for oil palm site selection, and for environmental planning in general, is characterized by a spatial component. Therefore, "such a DSS should be linked to a Geographic Information System (GIS) containing the relevant thematic layers" (Geneletti, 2004). Integrating GIS and DSS is now becoming a frequent strategy to dealing with decision problems related to environmental planning and land allocation (Carver, 1991; Herwijnen, 1999; Joerin et al., 2001; Keisler and Sundell, 1997; Malczewski, 1996; Pereira and Duckstein, 1993). GIS is also recognized worldwide in land use planning (such as (BojÓrquez-Tapia et al., 2001; Malczewski, 2004)).

GIS is a system used to collect, store, retrieve, integrate, analysis and display spatial and attribute data of the environment for particular purposes (Aronoff, 1989). However, the usual GIS do not provide the means to handle multiple decision factors (Farkas, 2009). According to (Farkas, 2009), a GIS-based system, combined with spatial multi-criteria decision analysis techniques may become more capable of transforming the geographical data into a decision. Spatial multi criteria evaluation is generally an important way to produce policy relevant information about spatial decision problems to decision makers processes (Sharifi and Retsios, 2004). Spatial multi criteria evaluation uses factors and constraints to decompose decision problems. A factor is a soft criterion that contributes to a certain degree to the output (suitability) and a constraint is a hard criterion that determines which areas should be excluded from or included in the suitability analysis (Zucca et al., 2008). "There are two types of factors: a benefit criterion which contributes positively to the output (the higher the values, the better it is), and a cost criterion which contributes negatively to the output (the lower the values, the better it is)", (Zucca et al., 2008). "As opposed to constraints, which cannot be compensated, poor performance of a factor can be compensated by a good performance of another factor", (Zucca et al., 2008)

Most spatial decision problems like the oil palm crisis in this case cannot be addressed without analyzing critically their driving causes. Below is a system's analysis approach of the oil palm crisis.

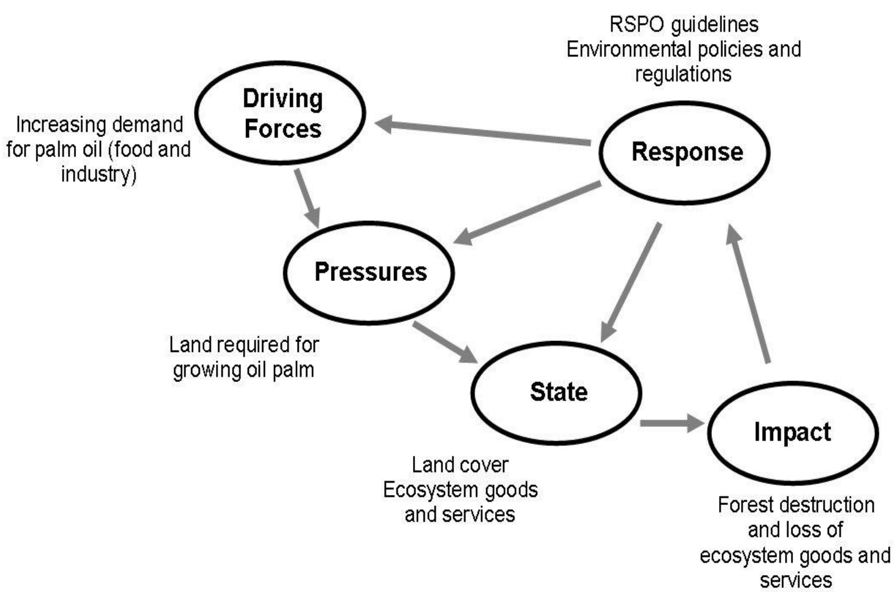


Figure 1: Conceptual framework showing oil palm in a system's approach
(Source: (van Duren et al., 2010) publication ("in prep")

The figure above clearly illustrates the main causes of the oil palm crisis and the initiatives the oil palm stakeholders have taken to deal with it. However, besides formulation of environmental policies and regulations: which are barely enforced, improved spatial planning will be very efficient in saving money and protecting the environment. Another initiative which has been widely stressed is compensation and mitigation which costs a lot of money especially for developing countries like Indonesia: one of the main palm oil producing countries.

Indonesia in particular has clear rules and regulations related to the use of forest land(Ministry of Foresty of Indonesia, 1985). However, these rules and regulations are not always enforced (Mantel. et al., 2007). In Indonesia, the designation of forest area is formulated based on integration and harmonization of Provincial Spatial Planning and Forest Land Use by Consensus Tata Guna Hutan Kesepakatan (TGHK), (Ministry of Foresty of Indonesia, 2010). In accordance to the Act on Forestry No. 41/1999, forest area is categorized as Conservation Forest, Protection Forest and Production Forest (Ministry of Foresty of Indonesia, 2010). However, most of these guidelines are not implemented while establishing new oil palm plantations.

Land suitability should therefore be taken into account in the decision making process since it plays an essential part in the planning process to locate land uses on the most optimal site. Some land suitability studies have been carried out worldwide as a strategy to deal with decision problems related to environmental planning and land allocation (Bello-Pineda et al., 2006); agriculture (Bello-Pineda et al., 2006; Bydekerke et al., 1998; Ceballos-Silva and López-Blanco, 2003a; Wandahwa and Van Ranst, 1996), waste disposal management (Basnet et al., 2001), recreational facilities setting (Kliskey, 2000) etc. However none had been carried out in Riau Province where a quarter of Indonesia's oil palm plantations are located. This detailed spatial information about sustainable oil palm expansion could support the government in designing a spatial planning policy for sustainable oil palm expansion.

The factors that could play a role in determining the suitability for oil palm expansion comprise physical terrain related aspects like; slope steepness and elevation that may cause accessibility and exploitation problems, as well as soil erosion with oil palm establishment (Mantel. et al., 2007). Terrain with slopes steeper than 40-45% is considered unsuitable for oil palm cultivation (Mantel. et al., 2007). Slopes less than 8% are optimal (Mantel. et al., 2007). For terrain with slopes between 9 and 30%, higher additional costs will be involved for land preparation (Mantel. et al., 2007). At altitudes between 500 to 1000 m sea level, oil palm production is constrained (Mantel. et al., 2007). Soil is another important factor that plays a role in determining the suitability for oil palm expansion. Oil palm can grow on a variety of soils (Mantel. et al., 2007). Sufficient water supply to the roots is the most important requirement for crop development and production (Mantel. et al., 2007).

Land use and ecology aspects are also important in the oil palm site selection process. For example; developable areas for oil palm expansion are mainly vacant land and other land uses that could be considered (e.g. grassland or rubber plantations) for oil palm expansion. However, expansion on agricultural land can reduce agricultural production of other crops (Mantel. et al., 2007). Also some forest areas have been identified as forests with High Conservation Value (HCV). Conversion of these forests is not allowed since these are forest areas that are in or contain rare, threatened or endangered ecosystems. Conversion of such forests could cause serious damage on the environment. If we aim at avoiding disturbance of HCVF, oil palm plantations should be established at a certain acceptable distance from HCVF. Protection of water sources to avoid the risk of pollution is another factor to consider in determining the suitability for oil palm expansion. It is thus reasonable to establish plantations within a defined distance to water sources especially where fertilizers are intended to be applied. The larger the distance from water bodies, the more suitable the area is for sustainable palm oil production. Mores so due to various functions of swamps and peat land areas on the environment, these areas are not suitable for sustainable oil palm growing. Besides they may be vulnerable to contamination.

Economic aspects are other important factors in determining the suitability of oil palm expansion. For example; potential sites should have good access to the transport services which can be defined within a certain distance from an existing main road. Therefore, those sites that exist farthest away from the existing roads are considered less suitable. More so, for easy accessibility to markets it is reasonable to establish plantations within a defined distance to settlements. This is based on the assumption that in every nearby settlement there is a market place. Therefore, those sites that exist farthest away from the nearby settlements are considered less suitable. It might also be convenient to establish new plantations close to existing ones especially for easy management purposes. These listed factors were used to design the questionnaire used in this study to solicit for more criteria from stakeholders.

However, it is a challenge to translate stakeholder opinions on relative importance of criteria into standardized value functions. Given the variety of scales on which attributes can be measured, multicriteria decision analysis requires that the scores of the various criteria are transformed to comparable units (Malczewski, 1999). Making the scores of the criteria comparable is often called standardization or normalization (Malczewski, 1999). Various methods to standardize scores are available: linear scale transformation methods like maximum standardization, interval standardization and goal standardization and also non−linear value function approach (Malczewski, 1999).

However according to (Beinat, 1997) most assessment techniques use curve fitting to specify the value function from the assessed point estimates. With curve fitting, the analytical form of the value function is explicit and appropriate for mathematical manipulation (Beinat, 1997). The number of points necessary for a good interpolation depends on the complexity of the value function, which unfolds throughout the assessment (Beinat, 1997). In most practical cases, three or four points are sufficient (Beinat, 1997; von Winterfeldt and Edwards, 1986): the case in this study. Polynomial, exponential or logarithmic fitting can be used for simple curves (Beinat, 1997; Keeney and Raiffa.H, 1976). The shape of such functions has a clear influence on the results of the standardization, and consequently of the overall evaluation (Beinat, 1997). For this reason, the value functions should be generated very carefully and if possible by resorting to the opinion of a group of experts (Beinat, 1997). In this study, the value functions were defined by an analytical expression by fitting a curve into the points that represent stakeholder views.

This study shows how stakeholder opinions can be used to develop and expand scenarios. This approach may help decision makers in analyzing which areas are most suitable for oil palm expansion according to different stakeholders and for which of these areas is common agreement among the stakeholders.

1.1. Research Objectives

The main objective of the study was to develop a decision support tool that may help governments in spatial planning for oil palm expansion.

And the specific objectives of this research were:

a. To identify a set of criteria that can be used to evaluate and compare stakeholder visions in the site selection of potential areas for sustainable oil palm expansion.

b. To set up a decision support tool for sustainable oil palm expansion.

c. To evaluate the level of agreement between stakeholders on the suitability ranking of potential expansion area

1.2. Research Questions

In order to achieve the research specific objectives above, the following research questions were addressed in this study;

For objective a:

- Which set of criteria can be used to evaluate stakeholder visions on sustainable oil palm expansion?

For objective b:

- Which value functions can be derived from stakeholder opinions on relative importance of criteria used for oil palm site selection?
- What are the differences between the stakeholder groups in criteria ranking?
- What are the sites that are most suitable for oil palm expansion in view of all stakeholder visions?

For objective c:

- Where are the sites where there is disagreement on suitability?

2. Materials and Methods

2.1. Study area

The area chosen for this study is Riau province located in Sumatra island of Indonesia (Sharma, 2009). Sumatra is the largest island of Indonesia and sixth largest in the world (Sharma, 2009; WWF, 2007). Indonesia, hosts some of the most biodiverse ecosystems on earth and unique species such as the critically endangered Sumatran tigers and Sumatran elephants (Uryu et al., 2008). The province is located along the Sumatra's northeastern coastline, near the city of Singapore across the strait of Malacca, between 0° N and 102° E (WWF, 2008a). The territorial size of Riau Province is 329,867.16 km consisting of land area 94,561,61 Km2 and water area 235,306,00 Km2 (Riau, 2010). Forest cover is approximately 20% of Sumatran land mass (Sharma, 2009; Sunderlin and Resosudarmo, 1996). "Sumatra has the majority of existing oil palm plantations of Indonesia, mainly located in four provinces: North Sumatra, Riau, South Sumatra and Jambi"(Erwidodo and Astana, 2004; Sharma, 2009). Riau was selected as the study area for this research because the expansion was the highest amongst all the provinces in Indonesia (Casson, 2003; Sharma, 2009).

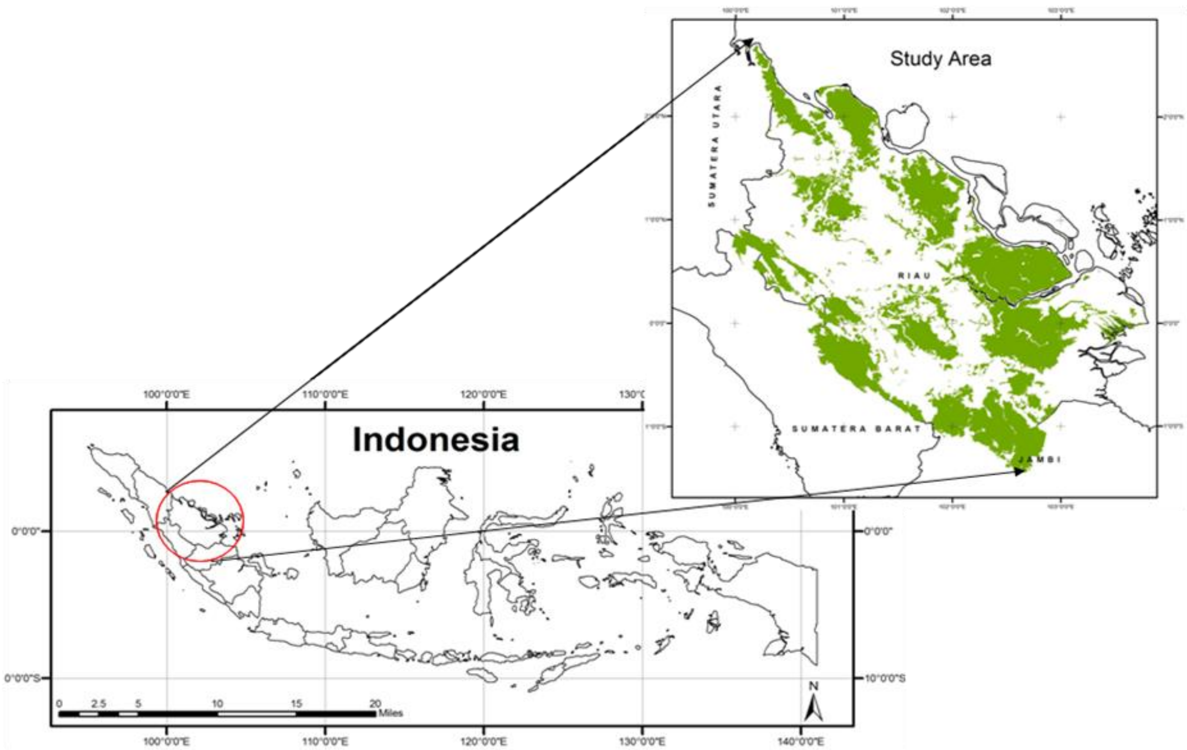


Figure 2: Location of the Study area: Areas of HCVF are highlighted in green
Source: Midora19256_MSc Thesis_NRM_2009

Climate

Riau province climate is tropical with dry (June to September) and rainy seasons (October to May), (Sharma, 2009). The precipitation ranges from 2000 to 3000 mm per year with approximately 160 days of rain (Sharma, 2009). The average temperature remains around 28°C throughout the year with the minimum of 23°C to 34°C (Sharma, 2009). Thus, the climate of Riau is very suitable for the growth of oil palm.

Land use

There are various land use types in Riau Province (Sharma, 2009). The area of the various land use and its percentage is given in the table below.

Table 2: Area in hectares and percentage of various land cover in Riau Province

Land cover	Area (hectares)	Area (%)
Acacia Plantation	1104073	10
Cleared land	260234	2
Natural forest	3618164	32
Oil palm plantations	1675698	15
Other land cover	1847751	17
Small holder oil palm plantations	488389	4
Wasteland	1195178	11
Water body	1002538	9

Source: (WWF, 2007)

Deforestation in Riau Province

Deforestation in Riau has been driven by various parties using destructive logging and forest clearance for development of settlements, infrastructure, agriculture, etc. But no other type of deforestation matches the speed and finality of forest conversion by the rapidly expanding pulp and paper and palm oil industries (WWF, 2008a). Between 1982 and 2007 these two industries replaced ca.2 million hectares of natural forest in Riau (WWF, 2008a).

2.2. Research methodology flow chart

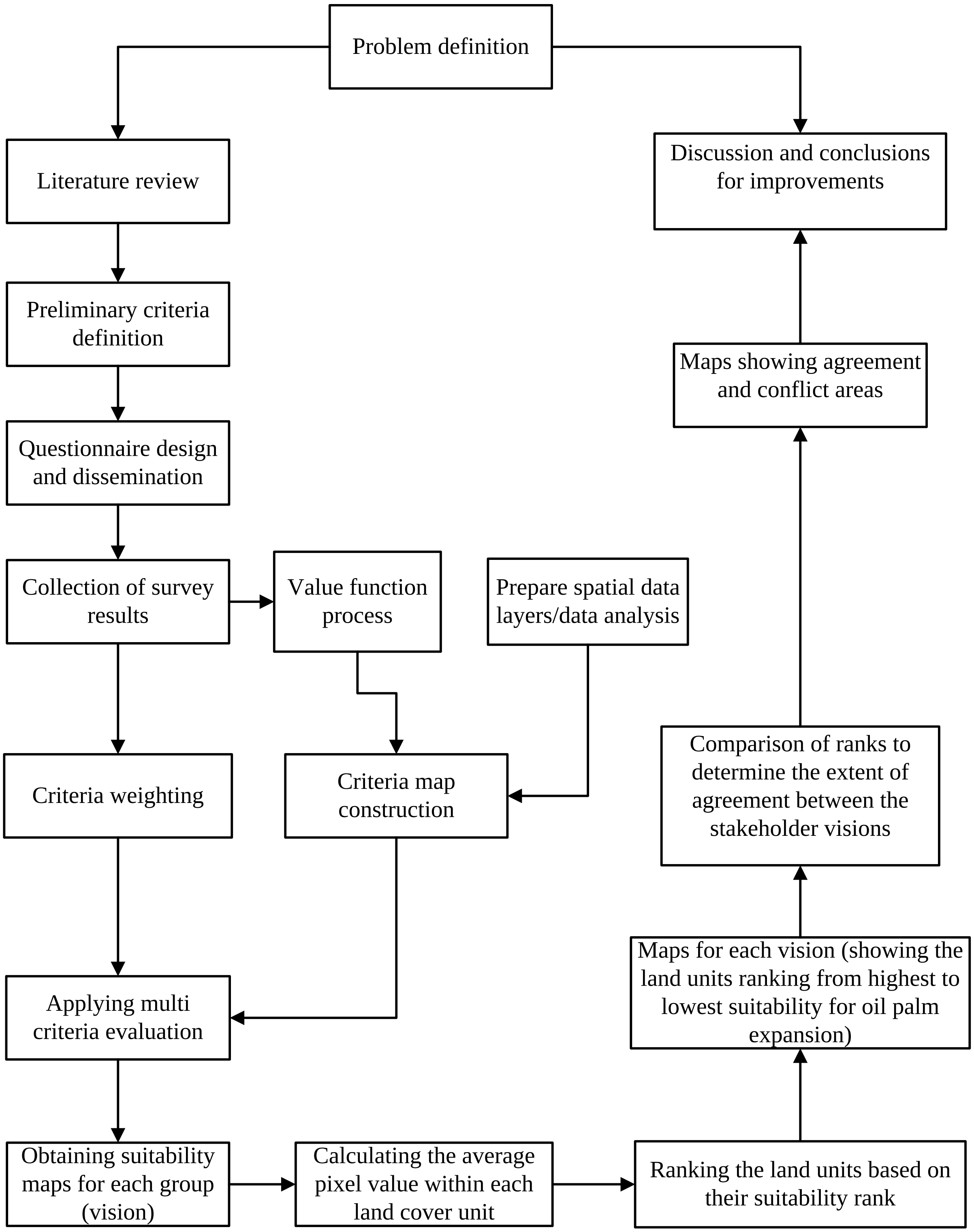


Figure 3: Research flow chart diagram

2.3. Research methodology

The general procedure that was followed in this study is shown in figure 3. The method involved several steps. A preliminary list of criteria relevant for oil palm site selection was defined based on literature review. This list of criteria was used to design questionnaires which were disseminated to selected stakeholders to solicit for more criteria relevant for oil palm site selection. During this phase, all the relevant spatial layers and primary data were collected and prepared. Value functions were developed to represent the views of each stakeholder vision on the relevant criteria for sustainable oil palm expansion. These included oil palm growers, government officials, conservationists and the overall vision. The first three stakeholder groups (oil palm growers, government officials and conservationists) were defined before the survey was carried out. After the survey some stakeholders did not belong to any of the specified groups hence leading to the formation of the fourth vision which included the views of all stakeholders (the overall vision). A multi criteria evaluation was performed to map the land suitability of four stakeholder visions. In the final phase, all data layers were combined resulting in a suitability map in which each pixel has a certain weighted cumulative value based on the criteria. Since managers, policy makers and planners cannot deal with pixels, I aggregated the average values for manageable units which were derived from the land cover map (WWF, 2007b). All the steps are explained in detail in the next sections.

2.4. Data collection methods

Two methods of data collection were used: data collection through primary sources and data collection through secondary sources. Below is the diagram for data collection methods used in the study.

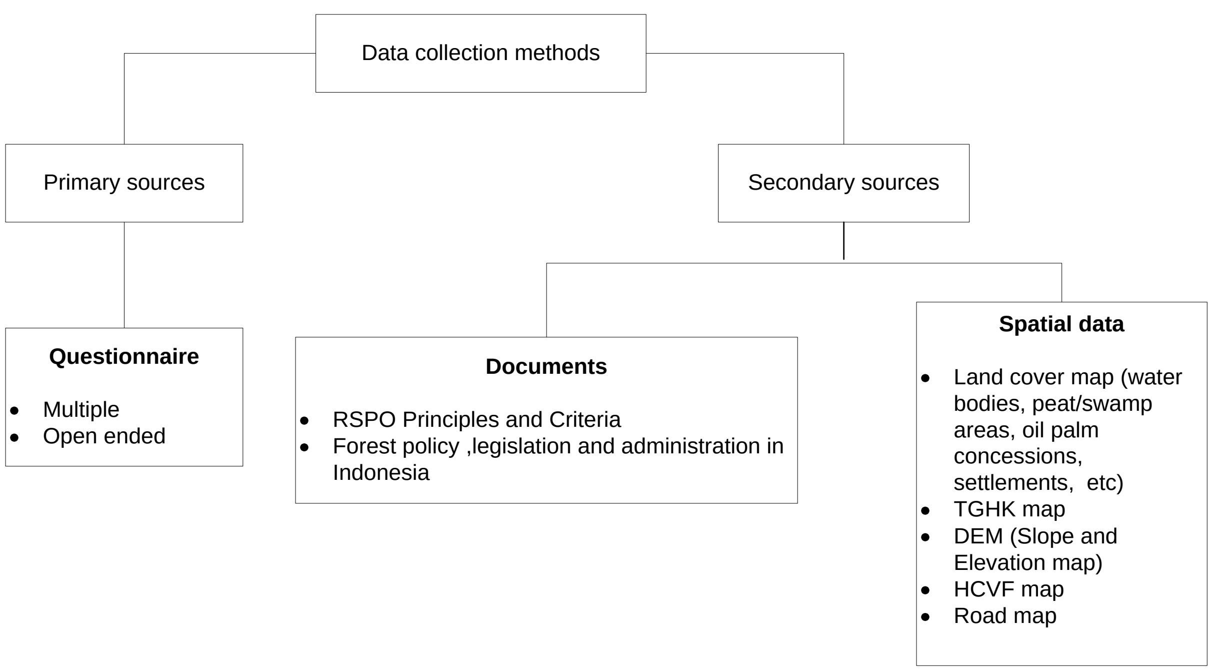


Figure 4: Data collection methods for the study

2.4.1. Secondary sources of data collection

Most of the spatial data used in the research was already available at the ITC; the rest was collected during the study. Some of it came from WWF Indonesia and others from the Ministry of forestry – Indonesia. The secondary sources included mainly the; internet, published books, journal articles, newspapers, seminar proceedings etc. Below is the list of the collected spatial layers (Table 3) and non-spatial data (Table 4).

Table 3: Collected spatial data

Name	**Data source**	**Format/ Year**	**Scale /resolution**	**Purpose for use**
Digital Elevation Model of Riau Province (Slope and Elevation Map)	http://srtm.csi.cgiar.org/	Raster	90m	Calculating slope gradient and elevation of the study area
Land cover map of the study area	WWF Indonesia	shape file 2007	1: 50,000	Classification analysis: to asses where land is high or low suitable for oil palm expansion
High Conservation Value Forests (HCVF) in Riau	WWF Indonesia	Shape file 2004	1: 50,000	Locating areas with HCVF
Water bodies	WWF Indonesia	shape file 2007	1: 50,000	Identifying water bodies
Protected areas map	http://www.sumatranforest.org/	Google images	1:150,000	Identifying protected areas like national parks
Map of Peat land/swamps in Riau	WWF Indonesia	shape file 2007	1: 50,000	Identifying areas with peat land and swamps
Map of oil palm concessions in Riau	WWF Indonesia	shape file 2007	1: 50,000	Assist the identification of existing oil palm plantations
Road networks of Riau Province	WWF Indonesia	Shape file 2007	1: 50,000	Road accessibility
Settlement map	WWF Indonesia	Shape file 2007	1: 50,000	Market accessibility

Table 4: Collected documents

Name	**Data source**	**Format/ Year**	**Purpose for use**
RSPO Principles and Criteria	Internet, Reports	Digital - 2008	Creation of decision rules for sustainable oil palm expansion
Forest policy ,legislation and administration in Indonesia	Ministry of forestry - Indonesia	Digital - 1985	To understand forest policies and legislations

2.4.2. Primary sources of data collection (Questionnaire survey)

The primary sources of data collection included mainly self-administered surveys using the designed questionnaire (see Appendix 1). The questionnaire was designed guided by the first list of criteria defined basing on literature review. This list was used in the questionnaire and respondents were given the opportunity to add more criteria and indicators. To ensure broad based data collection, multiple choice and open-ended questionnaires were administered to all selected stakeholders knowledgeable in sustainable oil palm production. First of all, a preliminary list of stakeholders was drawn, including oil palm growers, conservation NGO's, academicians/researchers, government officials, etc. The first list of stakeholders which included mostly oil palm growers and producers was got from the RSPO website (RSPO, 2009). The contacts of researchers were got from published articles. Conservationists and environmentalists were contacted through conservation NGOs like WWF Indonesia. Government stakeholders were accessed mainly through the ITC alumni network. These were former ITC students from Indonesia but currently working in different departments in the Indonesian government and are knowledgeable in palm oil production.

The Indonesian/English version of the questionnaire and a cover letter were distributed to all the stakeholders using the survey monkey software. This method was selected because it is very cost effective compared to other survey methods. The purpose of the survey, and the time required to complete the questionnaire were explained in the cover letter. Respondents were invited to provide additional remarks, criticism or recommendations. Confidentiality was emphasized and guaranteed as a strategy to increase the response rate. The survey started on 12th September and ended on 24th November, giving participants ample time to complete the survey. 584 questionnaires were distributed. One week before the requested deadline to respond, a reminder was sent to all the participants. Over 150 questionnaires were returned as undelivered. The questionnaire was composed of 24 questions. Out of 24 questions, 4 questions were open- ended and the remaining were multiple choices (Appendix: 1).

2.5. Data analysis

2.5.1. Analysis of spatial data

Data input into GIS were acquired in different formats, including graphic data, non-spatial information from both printed and digital files, and digital spatial data tapes such as digital elevation data as seen in Tables 3 & 4. All spatial criteria were prepared in ArcGIS Environment and converted to ILWIS for SMCE. The major tasks included geo-referencing some of the images, compiling and converting all the data to one defined projection. Projections were defined and transformed into the working coordinate systems.

2.5.2. Software packages used

Four Software packages were used in this study. These included; ArcMap, ILWIS, SPSS, and survey monkey. For digitizing, geo-referencing, rectification and other spatial operations ArcMap was used. For spatial multi-criteria evaluation ILWIS was used. For disseminating questionnaires, the survey monkey software was used: this being a desk top study. The statistical analyses of survey results were done using SPSS. The reasons are that ArcMap gives more capability in processing geographical shape file while ILWIS has a good SMCE processing unit. Yet all the soft-wares are also user-friendly.

2.5.3. Analysis of survey results

The answers from the questionnaire were analyzed using statistical software: Statistical Package for Social Sciences (SPSS) 16.0 and Microsoft Office Excel 2007. SPSS was used in order to reduce the possibility of error that may occur with operators unfamiliar with the format of the questionnaire. The data were checked for missing responses and entry errors through examination of frequency out puts. Missing data from incomplete questionnaires were entered as missing values.

Over 50% of the respondents answered only a part of the questionnaire (Appendix 1). The sub-group mean substitution method where the missing value is replaced by the mean on the subgroup of which the respondent is a member (Tsikriktsis, 2005), was used. To reduce the volume of data, simple statistical measures such as frequency, percentage, average etc were used, hence making it easier to understand. According to (Siegel and Castellan, 1988), it is also important to establish if the raters (in this case: oil palm stakeholders) have reached consensus. One way to measure consensus is to determine the degree of agreement among the raters in their judgments. The Kendall's coefficient of concordance (*W*) proposed by Maurice G. Kendall and Bernard Babington Smith was used to determine this agreement (Siegel and Castellan, 1988). Kendall Coefficient of Concordance must be between 0 and 1(Siegel and Castellan, 1988). *W* was computed using the formula below:

$$W = \frac{12\sum R_i^2 - 3K^2N(N+1)^2}{K^2N(N^2-1) - k\sum T_i}$$

Where:

R is the sum of ranks,

k the number of sets of rankings, e.g., the number of judges; in this case oil palm stakeholders,

N the number of objects (or individuals) being ranked, and,

T is a correction factor used when ties are observed.

Tied varieties were assigned the average rank they would have been assigned had no ties occurred and T was computed according to (Siegel and Castellan, 1988) using the formula below:

$$\mathrm{T}_j = \sum_{i=1}^{g_j} (\mathrm{t}_i^3 - \mathrm{t}_i)$$

Where t_i is the number of tied ranks in the *i*th grouping of ties and

g_i is the number of groups of ties in the *j*th set of ranks.

T_j is correction factor required for the *j*th set of ranks.

"The correction of ties results in a slight increase in the value of *W"* (Siegel and Castellan, 1988). The calculated *W* values shown in Table 12, were interpreted using the guidelines of (Schmidt, 1997) shown in Table 5.

Table 5: Interpretation of W values

W	Interpretation	Confidence in Rankings
0.1	Very weak agreement	None
0.3	Weak agreement	Low
0.5	Moderate agreement	Fair
0.7	Strong agreement	High
0.9	Unusually strong agreement	Very High

Source: (Okoli and Pawlowski, 2004; Schmidt, 1997)

However (Siegel and Castellan, 1988) suggests that the best estimate of the "true" ranking of the various variables is provided when *W* is significant, by the order of the various sums of ranks or, equivalently, the average rankings (Siegel and Castellan, 1988). In this study the average rankings for each stakeholder group were calculated as shown in Appendix 2 to identify the most preferred variable for each criterion. Seven of the criteria described concerned distance to the HCVF, water ways, peat and swamp areas, proximity to the main road, markets, and existing oil palm plantations.

2.5.4. Developing value functions

The average rankings (Appendix 2) were used to develop value functions to represent the preferences of the assessors (Figures 10 to 13). Before developing value functions, the average rankings were normalized to values between 0 and 1. The average rankings were normalized to make the maps comparable. The value of 1 indicates the most preferred or very suitable variable, while the value of 0 indicates the least preferred or unsuitable variable. For example, the value function for distance to oil palm plantations according to oil palm growers was developed through the following steps:

First the results from questionnaires were coded (1: very suitable, 2: suitable, 3: moderately suitable and 4: not Suitable) as seen in table 6 below, re-ranked to compute the average rankings (Table 7 below), and then normalized using the formula adopted from (Malczewski, 1999).

1- ((actual score – minimum score) / (Maximum score - minimum score))

The normalized values (Table 8) were used to fit a curve to describe best the relation between the variables (distance) and the standardized scores as shown in figure 6 below.

Table 6: Stakeholder rankings for distance to oil palm plantation criterion

No. of respondents	< 100 (m)	500 (m)	1 (Km)	5 (Km)	> 10 (Km)
1	1	2	2	2	3
2	4	3	2	1	1
3	2	2	2	3	3
4	1	1	2	3	3
5	3	3	3	3	3

Table 7: Re-ranked values basing on suitability

No. of respondents	< 100 (m)	500 (m)	1 (Km)	5 (Km)	> 10 (Km)
1	1	3	3	3	5
2	5	4	3	1.5	1.5
3	2	2	2	4.5	4.5
4	1.5	1.5	3	4.5	4.5
5	3	3	3	3	3
Sum	12.50	13.50	14.00	16.50	18.50
Average rankings	**2.50**	**2.70**	**2.80**	**3.30**	**3.70**

Table 8: Average rankings and normalized values for distance to oil palm plantations

Distance (m)	Average rankings	Normalized values
100	2.500	1.000
500	2.700	0.833
1000	2.800	0.750
5000	3.300	0.333
10000	3.700	0.000

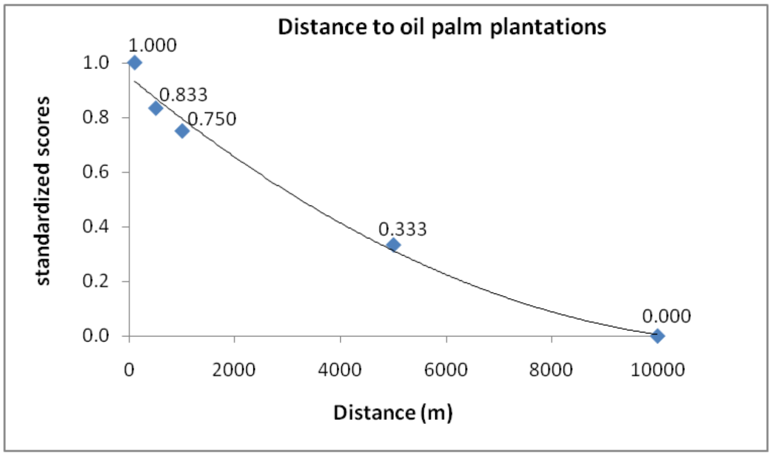


Figure 5: Value function for distance to oil palm plantations

$\boldsymbol{Y} = 6.600*10^{-9}x^2 - 1.602*10^{-4}x+9.492*10^{-1}$ $\quad$ $\boldsymbol{R^2} = 0.98$

This equation was used to write a script in ILWIS shown below to derive a standardized map of distance to oil palm plantation criterion (Appendix 4).

*OIL_PALM_TOP_O=min(1,max(0,0.0000000066*OIL_PALM_TOP_DIST.mpr*OIL_PALM_TOP_DIST .mpr-0.0001602380*OIL_PALM_TOP_DIST.mpr+0.9492035575))*

As seen in the example above, the X value in the function equation was replaced with the created distance maps for each respective criterion.

However, the computing capacity of ILWIS could not handle the size of the study area. For this purpose it was divided into three portions (TOP, BOTTOM RIGHT AND BOTTOM LEFT) implying that three scripts were written to account for each portion (Appendix 3). Later, three criteria trees were constructed to produce suitability maps for each portion which were later merged to derive final suitability maps for each group.

2.5.5. Weighting of the study criteria

Weight criteria show the relative importance of one criterion with respect to others. How criteria are weighted is based on the criteria rank obtained from stakeholder views. Therefore, for this study the weighting of various criteria was based on information obtained from the interviewing process and decision maker's preference. According to (Malczewski, 1999), the simplest method for assessing the importance of weights is to arrange them in rank order of a decision makers' preference. To generate a single value of criteria ranking for each criterion, as seen in Tables 11 to 14, the method developed by Jean-Charles de Borda (Cook and Seiford, 1982) was used. The rank sum method was finally used to establish weights for each criterion according to (Malczewski, 1999), as shown below:

$$W_i = \frac{n - rj + 1}{\sum(n - r_k \ + \ 1)}$$

Where;

w_i is the normalized weight for the for the *j*th criterion,

n is the number of criteria under consideration ($k = (1,2,,\ldots\ldots n)$, and,

r, is the rank position of the criterion

With this method, each rank is converted to a weight (the higher the weight, the more important the criteria), (Malczewski, 1999). Weight was given on the effectiveness of the criteria. Each criterion was given a score according to its suitability.

To establish the effect of change in criteria weights, two perspectives were adopted. These were the:

- Primary perspective which included initial weights as ranked by stakeholders and ,
- Equal weight perspective where all the criteria were given the same weight.

The equal weights were assigned to all the criteria to observe the effect of such changes to the overall output as seen in figures 16 to 17. The purpose of these changes was to explore how changes in perspective can lead to a compromise solution. The criteria trees were designed guided by the decision tree in figure 6 below. This decision tree structure was applied in mapping all the visions of all stakeholder groups.

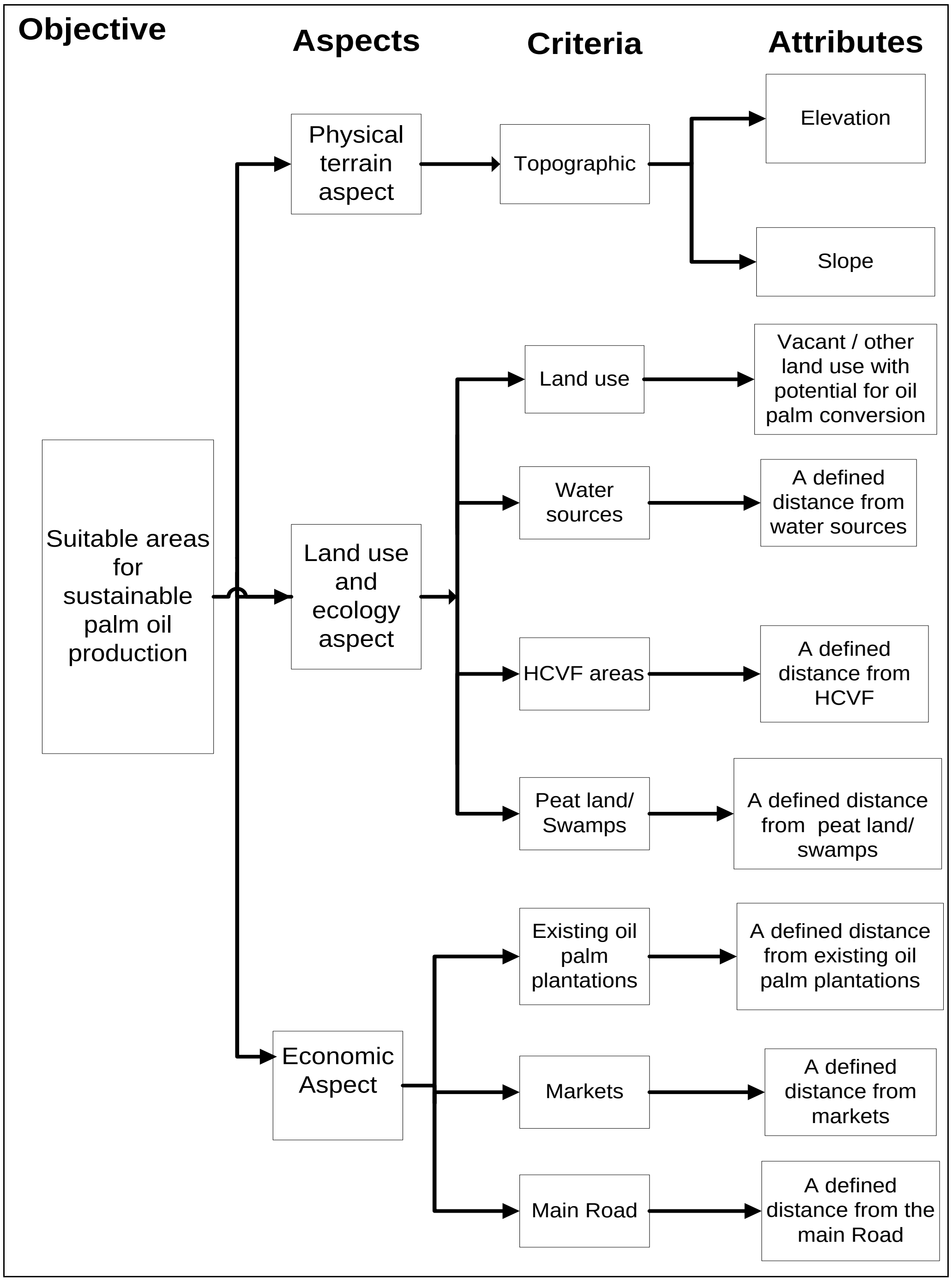


Figure 6: The decision tree developed for the oil palm site selection problem

2.5.6. Obtaining suitability maps

Once all the criteria maps for each stakeholder group were converted to partial suitability, standardized to the same value range, assigned their corresponding relative important weights, the overall suitability maps were generated for each stakeholder group (Figures 16 to 17). The preliminary step involved the identification of spatial constraints recognized by the stakeholders (e.g. HCVF, mangroves, peat/swamp areas, etc), and factors like distance to the main road, markets, etc. To this purpose, suitability maps for each stakeholder group were developed by following the typical steps of SMCE (Malczewski, 1999): factor normalization, weight assignment, and aggregation. Subsequently, the normalized factor maps were combined through weighted summation, according to the formula (Eastman et al., 1998):

$$S = \sum_{i=1}^{n} W_i X_i$$

Where:

S is the suitability score,

n the number of factors;

w_i the weight assigned to the factor *i*,

X_i is the normalized score of factor *i*.

This was facilitated by combining the various attributes for each pixel. The produced suitability maps showed the degree of pixel suitability sliced into 10 different levels of suitability within the range of 0 to 1 (Figure 16 and 17). To obtain information concerning the spatial distribution of suitability values, the average suitability pixel value for each land unit was calculated using the average aggregation method (Figure 18 and 19). The map used for this process contained only land cover types potential for oil palm expansion (Figure 10) selected based on expert knowledge and stakeholder views. Later all the average suitability ranks for each vision were compared to determine the level of agreement (Figure 20). Finally agreement and conflict areas for each perspective were identified together with the available amount of land (Figure 21 and 22).

3. Results

3.1. Identified stakeholder groups

This study aimed at involving as many stakeholders as possible from various professions (Table 9). Out of 584 participants contacted, only one hundred and twelve (112) responded (Table 9). Four stakeholder groups were specified to develop scenarios (Table 10).

Table 9: Survey respondents

Stakeholders	Number of Respondents
Oil Palm Growers	10
Palm Oil Producer/Seller	0
Researcher	31
Planner	14
Marketing	0
GIS specialist	9
Public Relations Officer	2
Lecturer / Teacher	12
Other	34
Total	**112**

Table 10: The research stakeholder groups

No.	Stakeholder	Number
1	Government stakeholders	32
2	Oil palm growers	10
3	Conservation stakeholders	33
4	Overall vision (all stakeholders)	112

3.2. Potential land cover types for oil palm expansion from stakeholder views

Stakeholders were asked in the questionnaire to specify land cover types they thought were suitable and unsuitable for oil palm expansion. Figures 7 and 8 shows maps representing their responses. Incidentally, all respondents agreed on particular land cover types as both suitable and unsuitable for oil palm expansion.

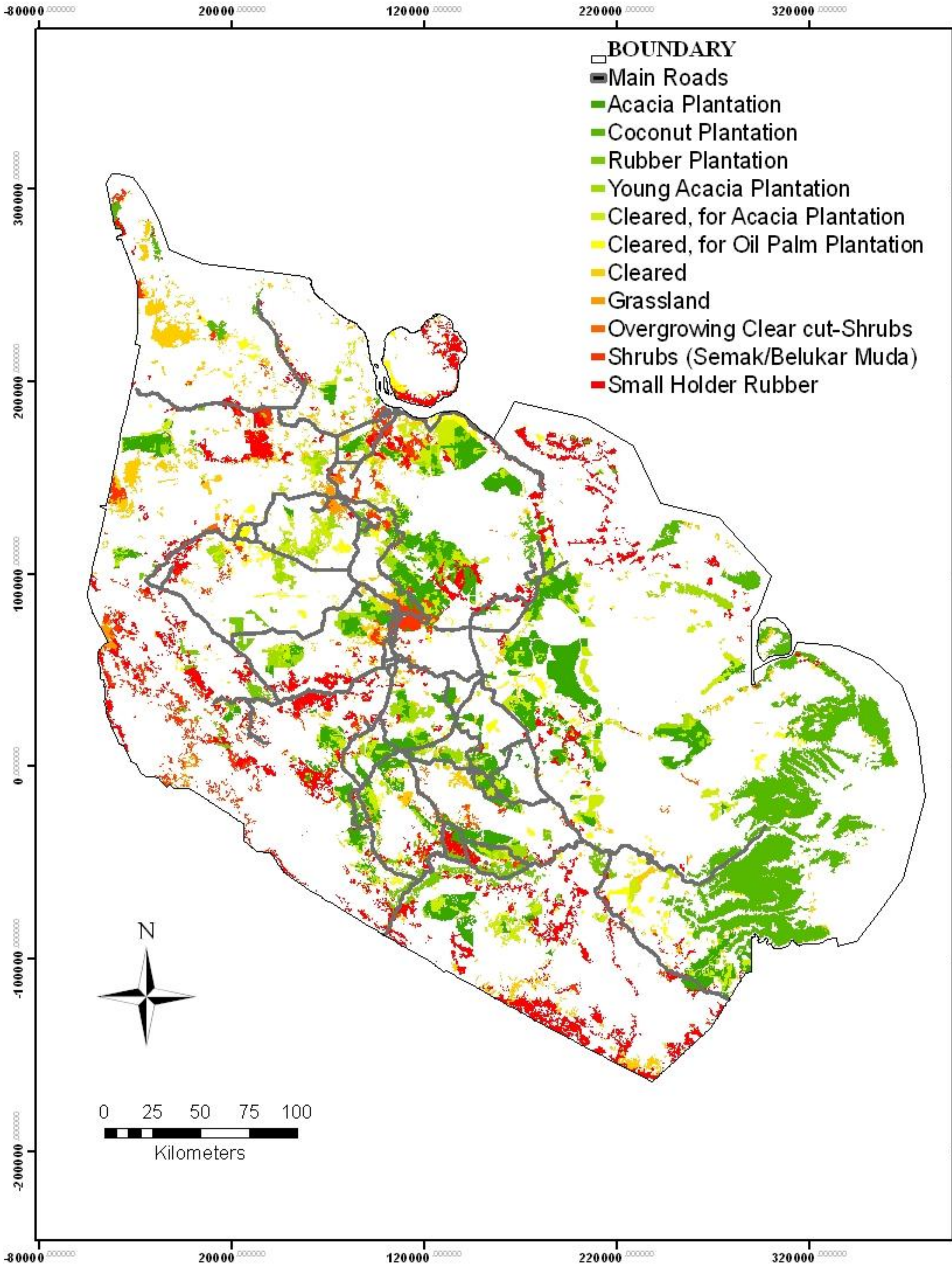


Figure 7: Potential land cover types for oil palm expansion according to stakeholder views

Source: (WWF, 2007b)

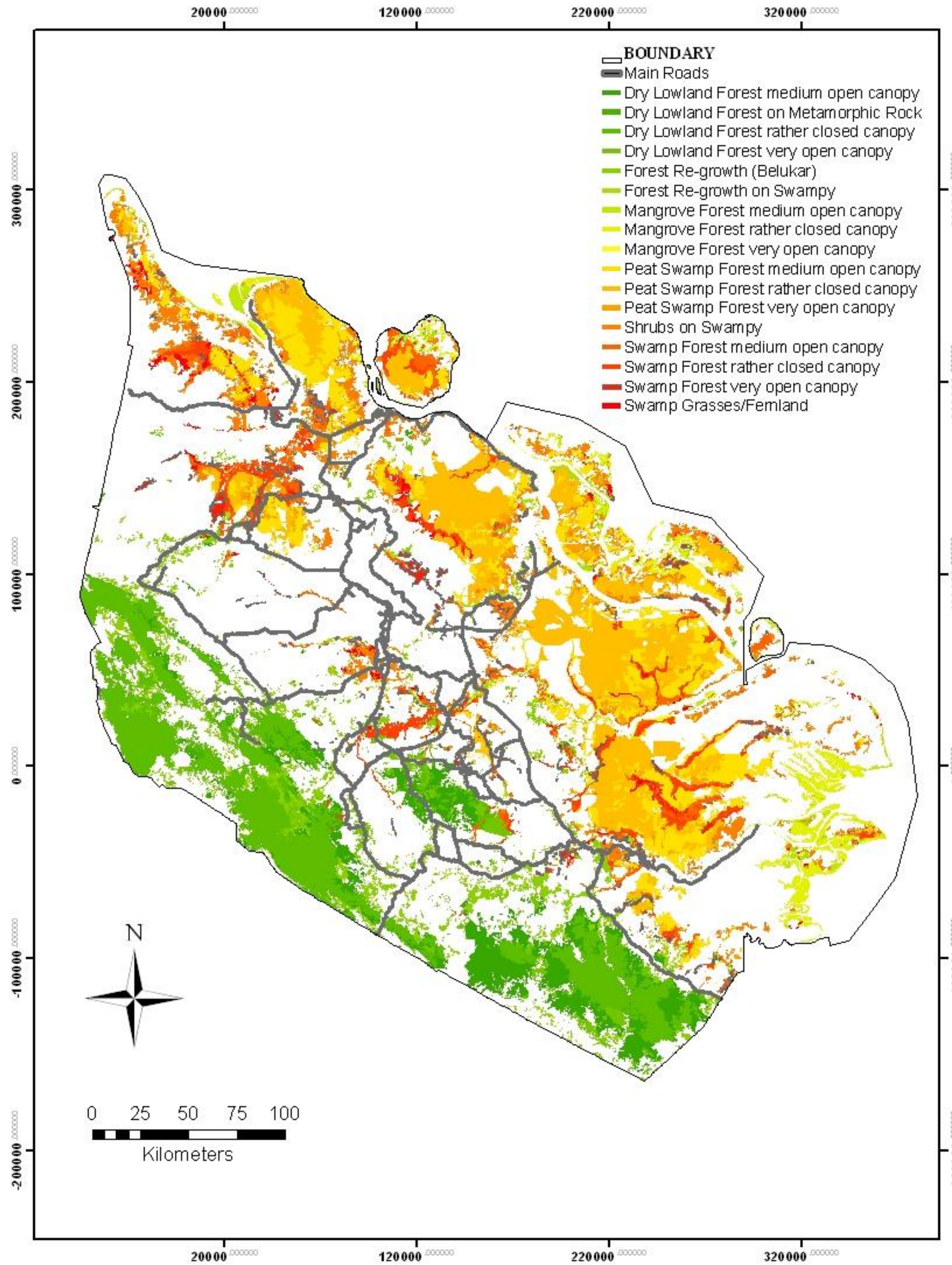


Figure 8: Land cover types not suitable for oil palm expansion according to stakeholder views
Source: (WWF, 2007b)

3.3. Land cover map showing potential land cover types for oil palm expansion

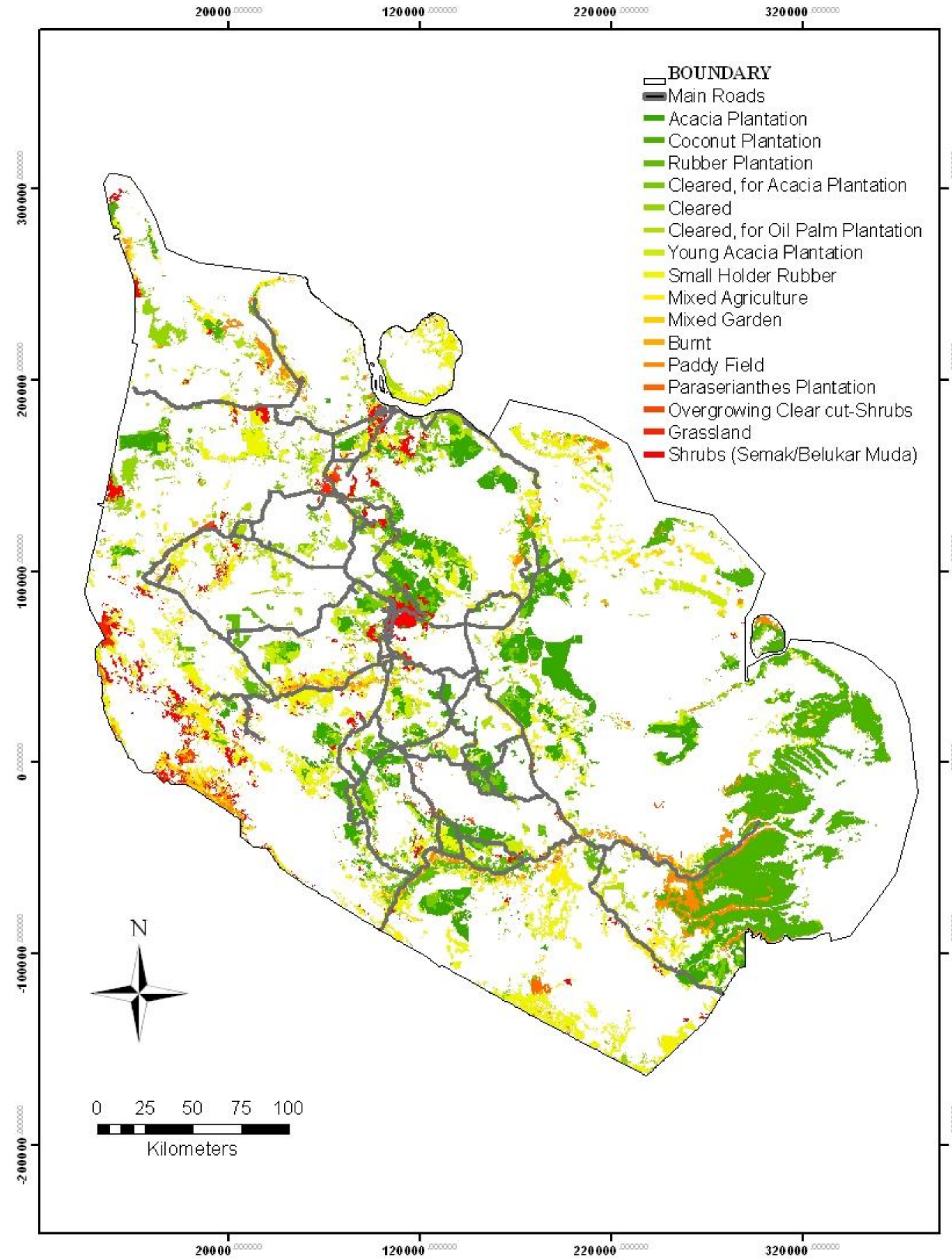


Figure 9: Potential land cover types for oil palm expansion
Source: (WWF, 2007b)

3.4. Identified criteria

The stakeholders identified more ten (10) factors as being relevant to sustainable oil palm expansion (Table 11). However, most of the additional criteria were non spatial criteria. Therefore the list of criteria with available spatial layers was used for further analysis.

Table 11: Defined criteria for oil palm site selection

No.	Criteria
1.	Distance to High Conservation Value Forests (HCVF)
2.	Distance to natural forests
3.	Distance to peat land/swamps
4.	Distance to water sources
5.	Proximity to existing oil palm plantations
6.	Proximity to main roads
7.	Proximity to market areas
8.	Slope steepness
9.	Elevation
10.	Soil Structure
11.	General Land use
12.	Proximity to oil mills or factories
13.	Proximity to high vulnerable disaster areas i.e. soil erosion susceptible areas
14.	Labour availability
15.	Legality of the land /land ownership
16.	Full Impact Assessment
17.	Economic viability
18.	Prior informed consent of affected communities
19.	A fully developed environmental management system
20.	Where there is poverty and unemployment
21.	Precipitation

The criteria which had spatial layers were classified as shown in the table below basing on their type.

Table 12: Types of criteria

Criteria	Type of criteria
Slope steepness	Constraint / Factor
Elevation	Constraint / Factor
Land use	-
Distance to HCVF	Constraint / Factor
Distance to water sources	Constraint / Factor
Distance to peat land /Swamps	Constraint / Factor
Distance to main road	Constraint / Factor
Distance to market places	Factor
Distance to existing oil palm plantations	Constraint / Factor

3.5. The Kendall coefficient of concordance *W* results

Table 13 shows Kendall coefficient of concordance results calculated to determine the degree of consensus among stakeholders in ranking all the criteria. The coefficient of concordance among oil palm stakeholders was highly significant in ranking most criteria especially the physical terrain related aspect and land use/ecology aspect. It was not significant in most economic criteria since they received the lowest *W* values.

Table 13: Agreement among stakeholder groups

Criteria	***W* values**			
	Overall Vision	Conservation	Government	Oil Palm growers
Physical terrain related aspect				
Slope steepness	0.780	0.719	0.804	0.871
Elevation	0.840	0.745	0.813	0.981
Land use and Ecology aspect				
Distance to water bodies	0.680	0.698	0.669	0.917
Distance to swamps and peat areas	0.630	0.625	0.470	0.948
Distance to HCVF	0.620	0.625	0.551	0.758
Economic aspect				
Distance to markets	0.120	0.497	0.488	0.139
Distance to existing oil palm plantations	0.300	0.131	0.106	0.009
Distance to the main road	0.430	0.660	0.273	0.545

3.6. Developed value functions for each stakeholder group

Below is a list of curves fitted for each criterion according to the four stakeholder visions (Figure 10 to 13). The best fitting curve was used to best represent the relationship between variables and standardized scores. Tables 14 to 17 represent the equations used to write scripts in ILWIS (see Appendix 3) to derive source maps for the site selection process. Examples of the standardized maps are listed in appendix 4.

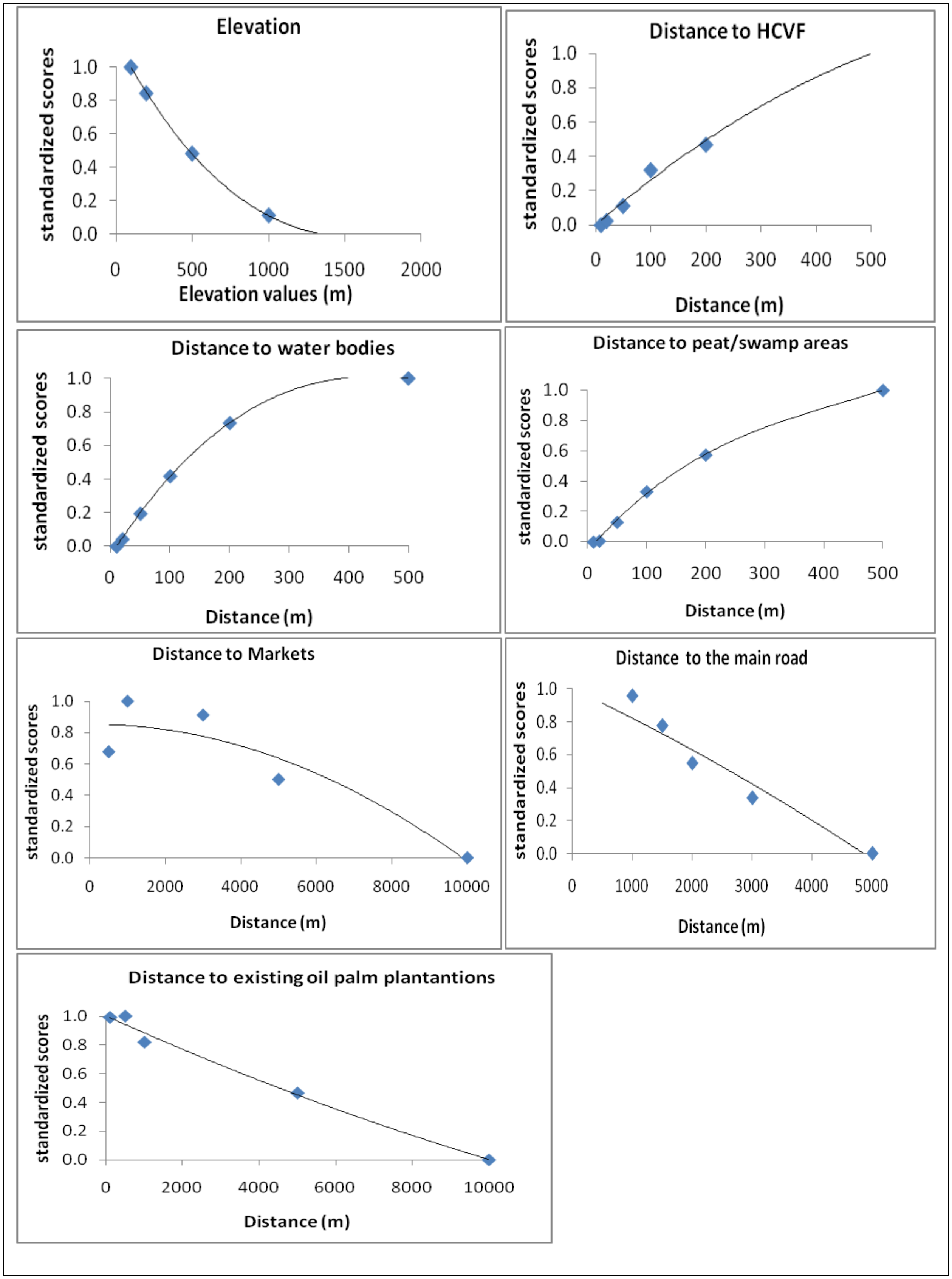


Figure 10: Value functions from the overall vision

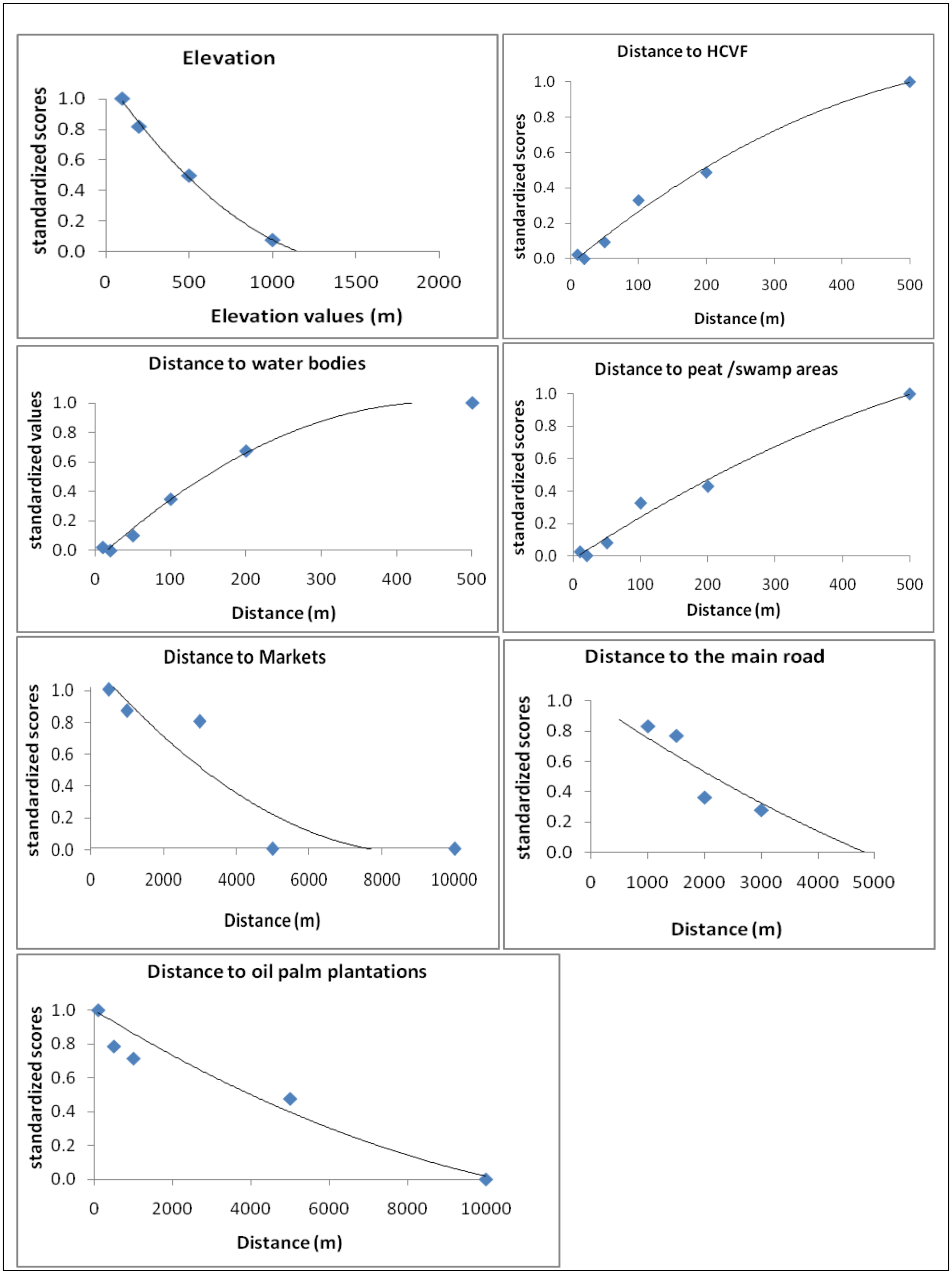


Figure 11: Value functions from conservation stakeholders

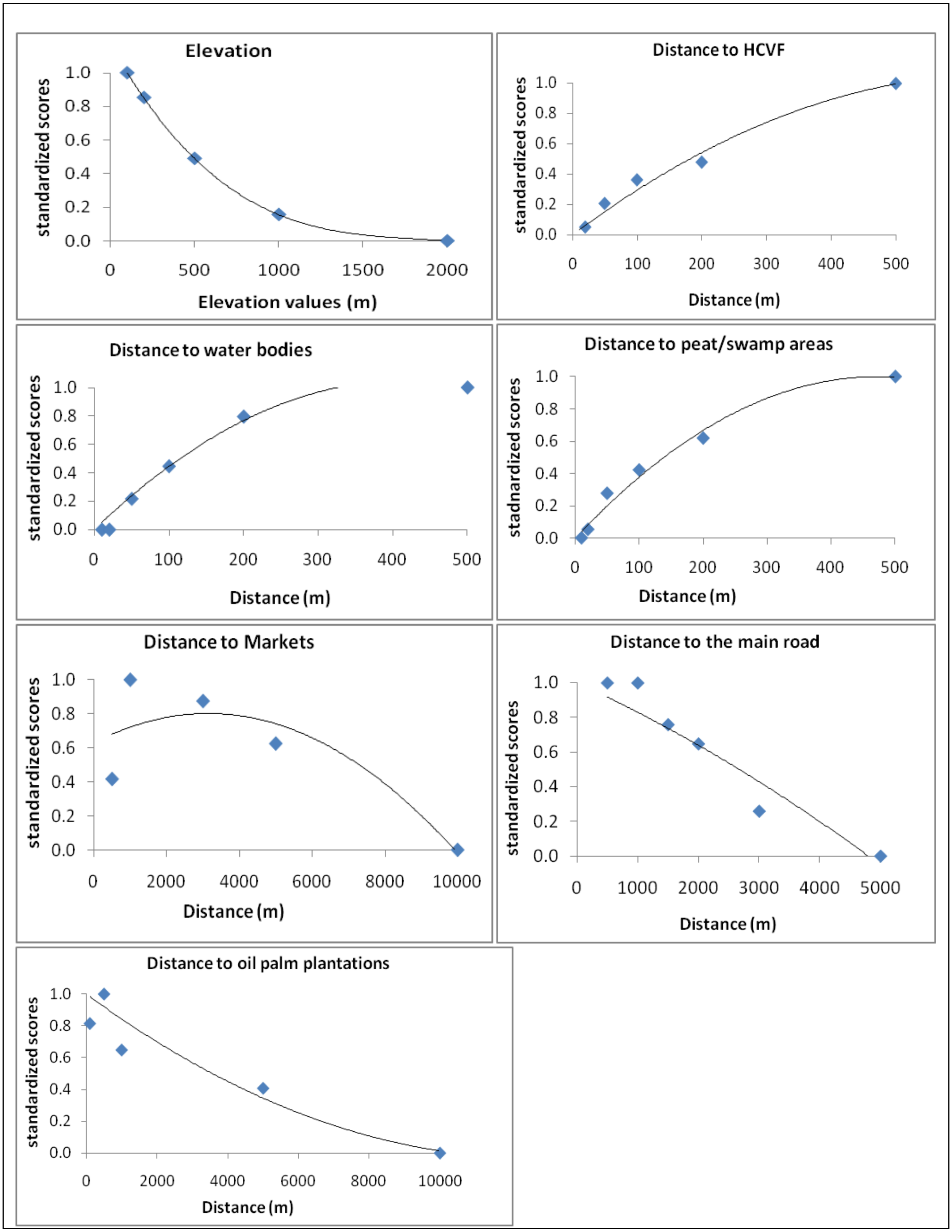


Figure 12: Value functions from government stakeholders

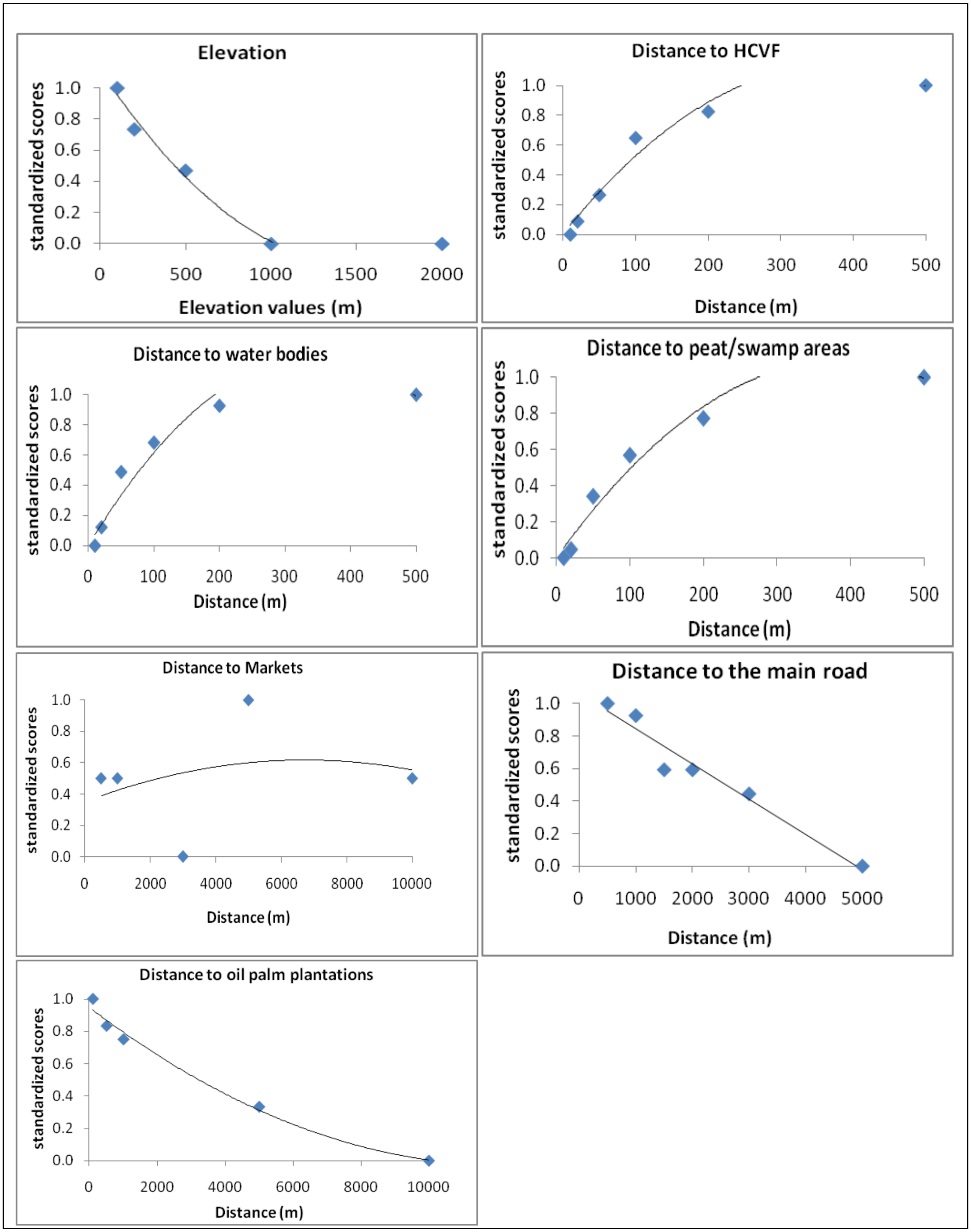


Figure 13: Value functions from oil palm growers

Table 14: Equations for the overall vision value functions

Criteria	Equations	R^2
Elevation	$y=-1.076*10^{-10}x^3+7.919*10^{-7}x^2- 1.735*10^{-3}x + 1.164$	1.00
Distance to water bodies	$y=3.864*10^{-9}x^3-8.900*10^{-6}x^2+5.606*10^{-3}x-6.072*10^{-2}$	0.09
Distance to peat/swamps	$y=6.152*10^{-9}x^3 -7.906*10^{-6}x^2+ 4.543*10^{-3}x -6.442*10^{-2}$	0.99
Distance to HCVF	$y=-1.565*10^{-6}x^2 + 2.779*10^{-3}x$	0.99
Distance to markets	$y=-8.822*10^{-9}x^2+8.149*10^{-7}x + 8.532*10^{-1}$	0.85
Distance to Oil palm plantations	$y=2.036*10^{-9}x^2-1.204*10^{-4}x+ 1.004$	0.99
Distance to Road	$y=-7.105*10^{-9}x^2-1.710*10^{-4}x+ 1.000$	0.94

Table 15: Equations for conservation value functions

Criteria	Equations	R^2
Elevation	$y =4.896*10^{-7}x^2 -1.546*10^{-3}x + 1.133$	0.99
Distance to water bodies	$y =-5.058*10^{-6}x^2 + 4.679*10^{-3}x – 7.341*10^{-2}$	0.99
Distance to peat/swamps	$y = -1.402*10^{-6}x^2 + 2.736*10^{-3}x – 2.091*10^{-2}$	0.98
Distance to HCVF	$y = -2.280*10^{-6}x^2 + 3.197*10^{-3}x – 3.093*10^{-2}$	0.99
Distance to markets	$y = 1.441*10^{-8}x^2 – 2.644*10^{-4}x + 1.174$	0.86
Distance to Oil palm plantations	$y = 4.495*10^{-9}x^2 – 1.431*10^{-4}x + 1.000$	0.92
Distance to Road	$y = 9.637*10^{-9}x^2 – 2.536*10^{-4}x + 1.000$	0.91

Table 16: Equations for government value functions

Criteria	Equations	R^2
Elevation	$y = -1.737*10^{-10}x^3 + 9.505*10^{-7}x^2 – 1.792*10^{-3}x + 1.172$	1.00
Distance to water bodies	$y = -6.106*10^{-6}x^2 + 5.061*10^{-3}x$	0.98
Distance to peat/swamps	$y = -4.488*10^{-6}x^2 + 4.233*10^{-3}x$	0.98
Distance to HCVF	$y = -2.410*10^{-6}x^2 + 3.192*10^{-3}x$	0.98
Distance to markets	$y = -1.745*10^{-8}x^2 + 1.098*10^{4}x + 6.271*10^{-1}$	0.74
Distance to oil palm plantations	$y = 6.448*10^{-9}x^2 – 1.631*10^{-4}x + 1.000$	0.87
Distance to Road	$y = -1.008*10^{-8}x^2 - 1.597*10^{-4}x + 1.000$	0.92

Table 17: Equations for oil palm growers' value functions

Criteria	Equations	R^2
Elevation	$y=5.4*10^{-7}x^2–1.647*10^{-3}x+ 1.116$	0.99
Distance to water bodies	$y=-1.043*10^{-5}x^2 + 7.193*10^{-3}x$	0.95
Distance to peat/swamps	$y=-7.333*10^{-6}x^2+ 5.653*10^{-3}x$	0.97
Distance to HCVF	$y=-8.169*10^{-6}x^2+ 6.073*10^{-3}x$	0.97
Distance to markets	$y=-5.873*10^{-9}x^2+7.893*10^{-5}x+ 3.510*10^{-1}$	0.64
Distance to oil palm plantations	$y=6.600*10^{-9}x^2-1.602*10^{-4}x+9.492*10^{-1}$	0.99
Distance to Road	$y=-2.153*10^{-4}x+1.059$	0.95

3.7. Ranking of the criteria

All stakeholders were asked to rank the defined criteria based on how relatively important one criterion was to others. Tables 18 to 21 show how each stakeholder group ranked different criteria. A rank of 1 represented extremely important, 2 very important, 3 important, 4 moderately important and rank 5 represented not important.

Table 18: Criteria ranking from the overall vision (all stakeholders)

Criteria	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	No. of respondents
Slope steepness	10	19	11	5	0	45
Elevation	8	12	20	5	0	45
Land use	16	14	9	6	2	47
Distance to water bodies	13	19	9	6	2	49
Distance to swamps and peat areas	13	20	7	6	1	47
Distance to HCVF	34	4	6	2	3	49
Distance to existing oil palm plantations	3	5	16	9	12	45
Distance to markets	3	6	16	13	8	46
Distance to the main road	6	12	13	12	2	45

Table 19: Criteria ranking by government stakeholders

Criteria	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	No. of respondents
Slope steepness	1	6	3	3	0	13
Elevation	2	4	6	1	0	13
Land use	3	2	4	3	1	13
Distance to water bodies	4	7	1	1	0	13
Distance to swamps and peat areas	4	3	3	3	0	13
Distance to HCVF	5	1	3	1	3	13
Distance to existing oil palm plantations	3	0	6	1	3	13
Distance to markets	2	2	4	4	1	13
Distance to the main road	2	4	4	3	0	13

Table 20: Criteria ranking by conservation stakeholders

Criteria	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	No. of respondents
Slope steepness	5	6	2	0	0	13
Elevation	3	5	5	0	0	13
Land use	8	1	4	1	1	15
Distance to water bodies	5	4	4	3	0	16
Distance to swamps and peat areas	6	6	0	1	1	14
Distance to HCVF	13	1	1	1	0	16
Distance to existing oil palm plantations	0	2	3	3	5	13
Distance to markets	0	2	3	6	3	14
Distance to the main road	0	4	3	5	1	13

Table 21: Criteria ranking by oil palm growers

Criteria	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	No. of respondents
Slope steepness	1	3	1	0	0	5
Elevation	0	0	4	1	0	5
Land use	1	3	0	1	0	5
Distance to water bodies	0	2	1	1	1	5
Distance to swamps and peat areas	1	2	1	1	0	5
Distance to HCVF	5	0	0	0	0	5
Distance to oil palm plantations	0	0	3	1	1	5
Distance to markets	0	0	1	3	1	5
Distance to the main road	0	1	1	3	0	5

From these results (Table 18 to 21), the rank order for each criterion was derived using the borda count method. Tables 22 to 25 show criteria rankings of each stakeholder group.

Table 22: Criteria rank from the overall vision

		Overall vision
Borda count	Rank	Criteria
162	1	Distance to HCVF
133	2	Distance to water bodies
132	3	Distance to swamps and peat areas
130	4	Land use
124	5	Slope steepness
113	6	Elevation
98	7	Distance to the main road
75	8	Distance to markets
68	9	Distance to existing oil palm plantations

Table 23: Criteria rank from government stakeholders

		Government stakeholders
Borda Count	Rank	Criteria
40	1	Distance to water bodies
34	2	Distance to swamps and peat areas
33	3	Elevation
31	4	-Distance to the main road -Slope steepness
30	5	Distance to HCVF
29	6	Land use
26	7	Distance to markets
25	8	Distance to existing oil palm plantations

Table 24: Criteria rank from conservation stakeholders

		Conservation stakeholders
Borda count	Rank	Criteria
58	1	Distance to HCVF
44	2	-Land use -Distance to swamps and peat areas
43	3	Distance to water bodies
42	4	Slope steepness
37	5	Elevation
23	6	Distance to the main road
18	7	Distance to markets
15	8	Distance to existing oil palm plantations

Table 25: Criteria rank from oil palm growers

		Oil palm growers
Borda count	Rank	Criteria
20	1	Distance to HCVF
15	2	Slope steepness
14	3	Land use
13	4	-Distance to swamps and peat areas -Distance to water bodies
9	5	Elevation
8	6	Distance to the main road
7	7	Distance to existing oil palm plantations
5	8	Distance to markets

3.8. Criteria weighting results

The borda count results (Tables 22 to 25) were used to calculate weights for each criterion using the rank sum method as seen in Table 26.

Table 26: Weight of factor criteria

	Normalized weights			
Criteria	Overall vision	Government	Conservation	Oil palm growers
Slope steepness	0.111	0.120	0.118	0.163
Elevation	0.089	0.140	0.098	0.102
Land use	0.133	0.080	0.157	0.143
Distance to water bodies	0.178	0.180	0.137	0.102
Distance to swamps and peat areas	0.156	0.160	0.137	0.122
Distance to HCVF	0.200	0.100	0.176	0.184
Distance to existing oil palm plantations	0.022	0.040	0.039	0.061
Distance to markets	0.044	0.060	0.059	0.041
Distance to the main road	0.067	0.120	0.078	0.082

3.9. Constructed criteria trees

The weights in table 26 were used to create criteria trees for the primary perspective. For the equal weight perspective all the criteria for each vision were given the same weight (1). Examples of both created trees are shown in figure 14 and 15. The rest are in Appendix 5.

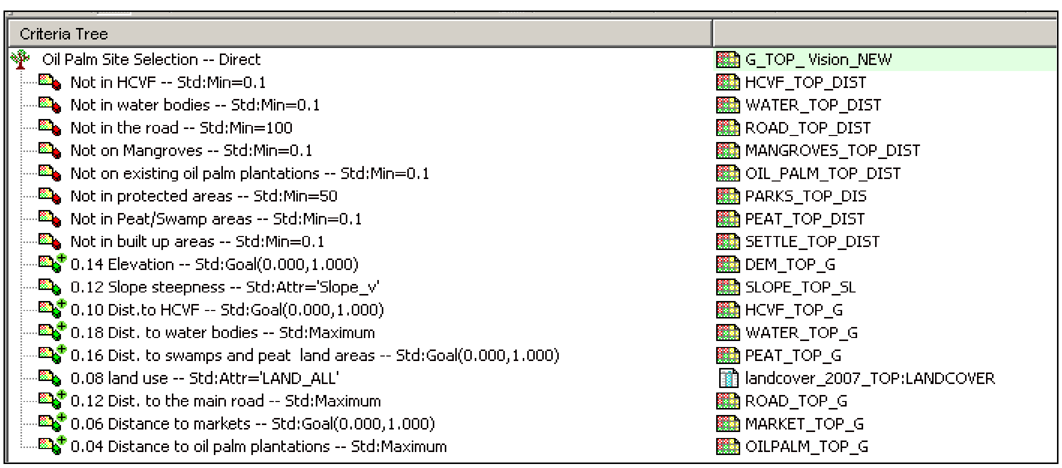


Figure 14: A screen shot of a criteria tree for the primary perspective: Government stakeholders

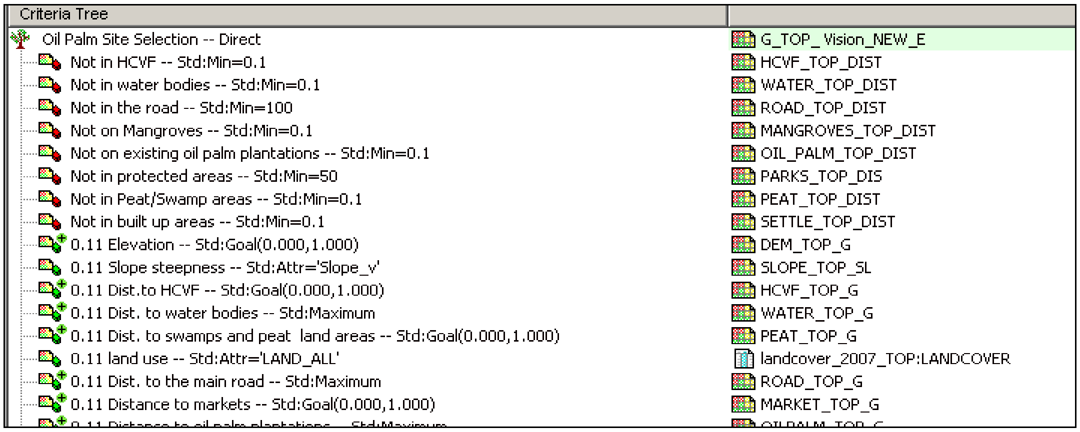
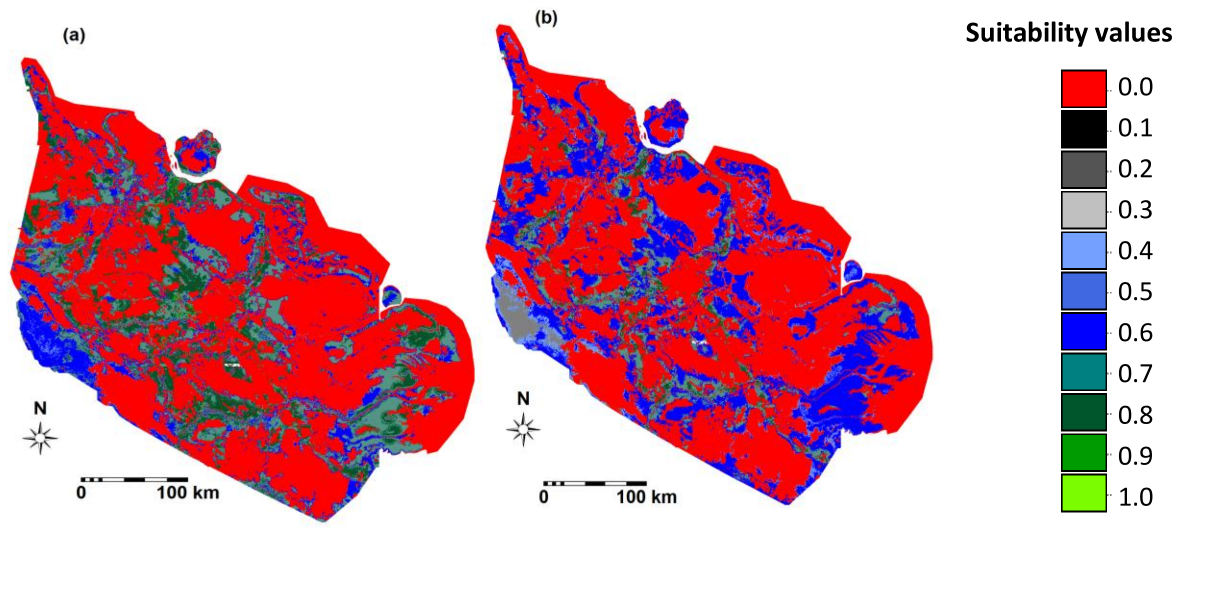


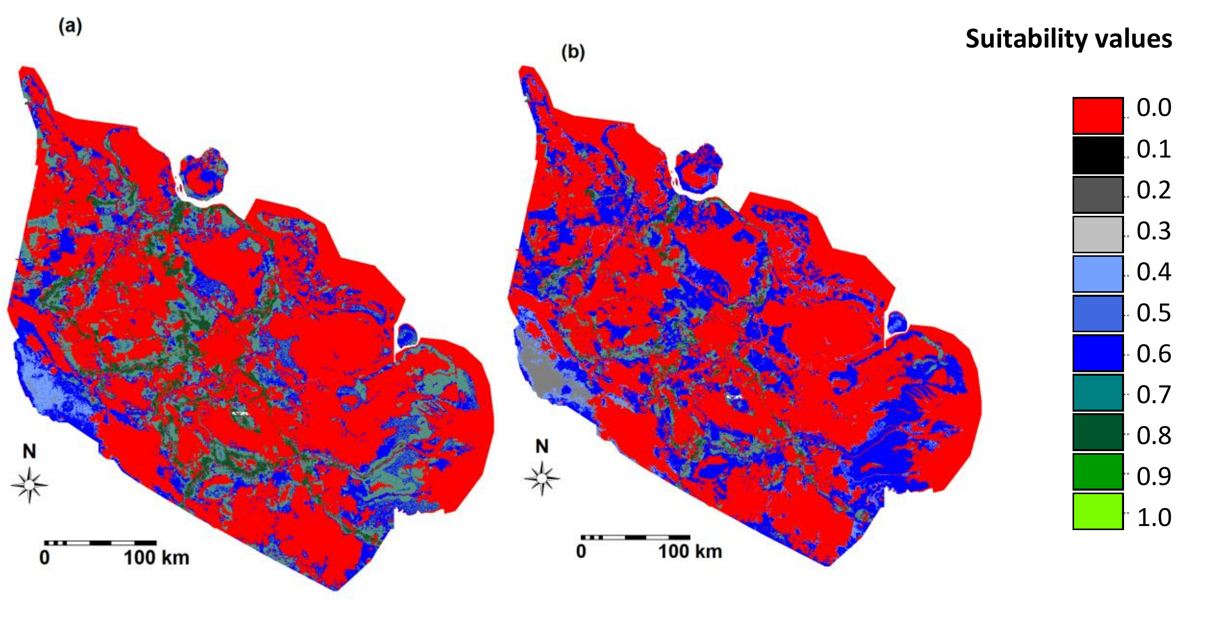
Figure 15: A screen shot of a criteria tree for the equal weight perspective: Government stakeholders

3.10. Developed suitability maps

Suitability maps seen in figures 16 and 17 were produced for each group. A value of 0 represents unsuitable areas where as a value of 1 represents the most suitable or potential areas for sustainable oil palm expansion.

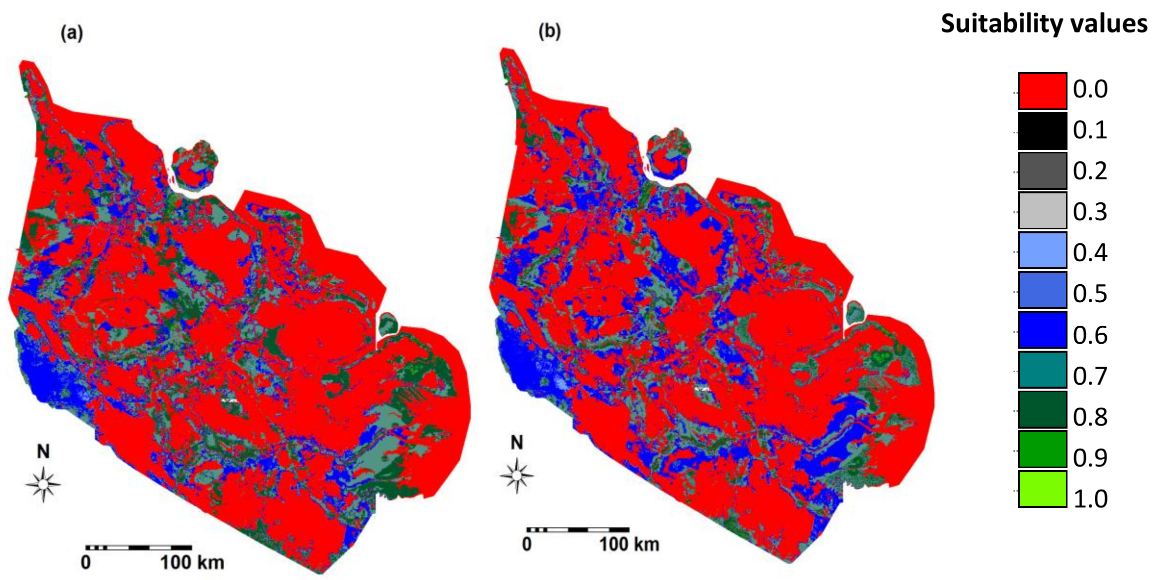


Overall vision: (a) primary perspective and (b) equal weight perspective

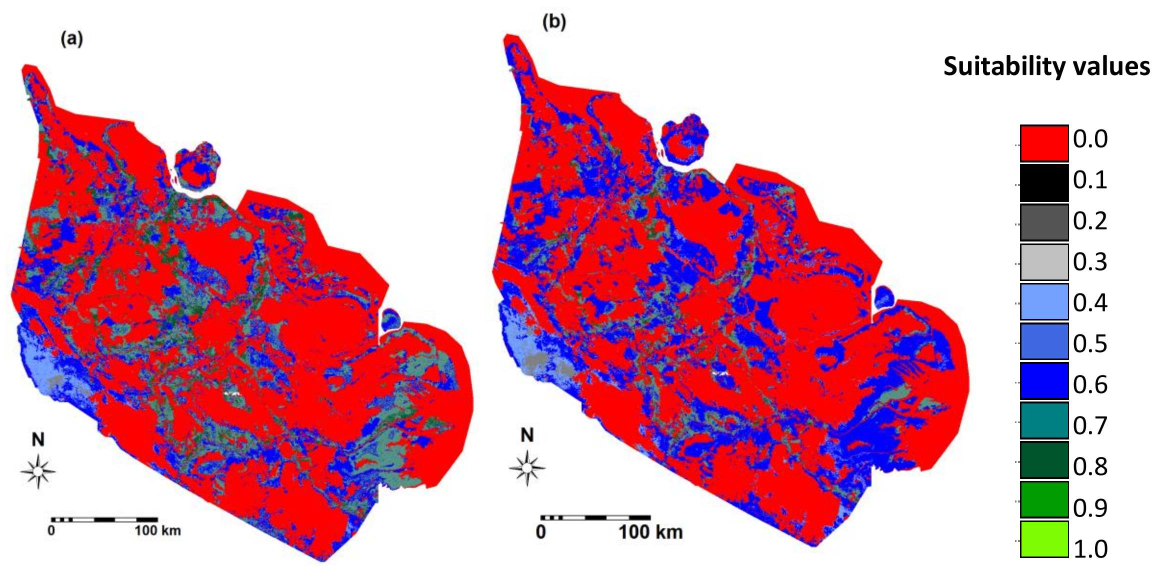


Government stakeholders: (a) primary perspective and (b) equal weight perspective

Figure 16: Suitability maps from the overall and government vision



Conservation stakeholders: (a) primary perspective and (b) equal weight perspective

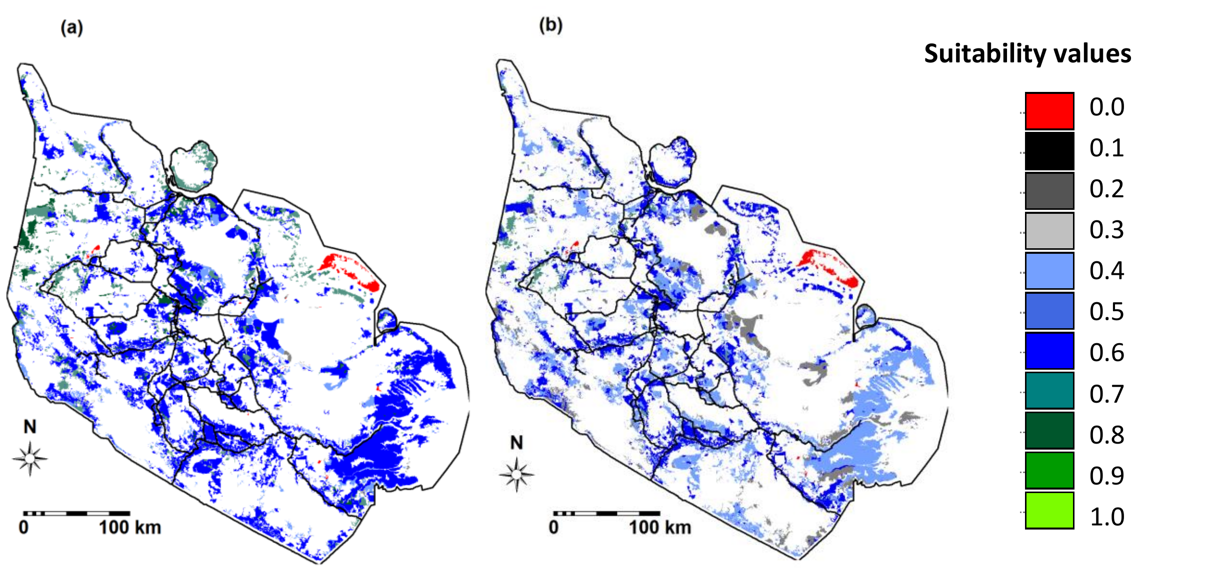


Oil palm growers: (a) primary perspective and (b) equal weight perspective

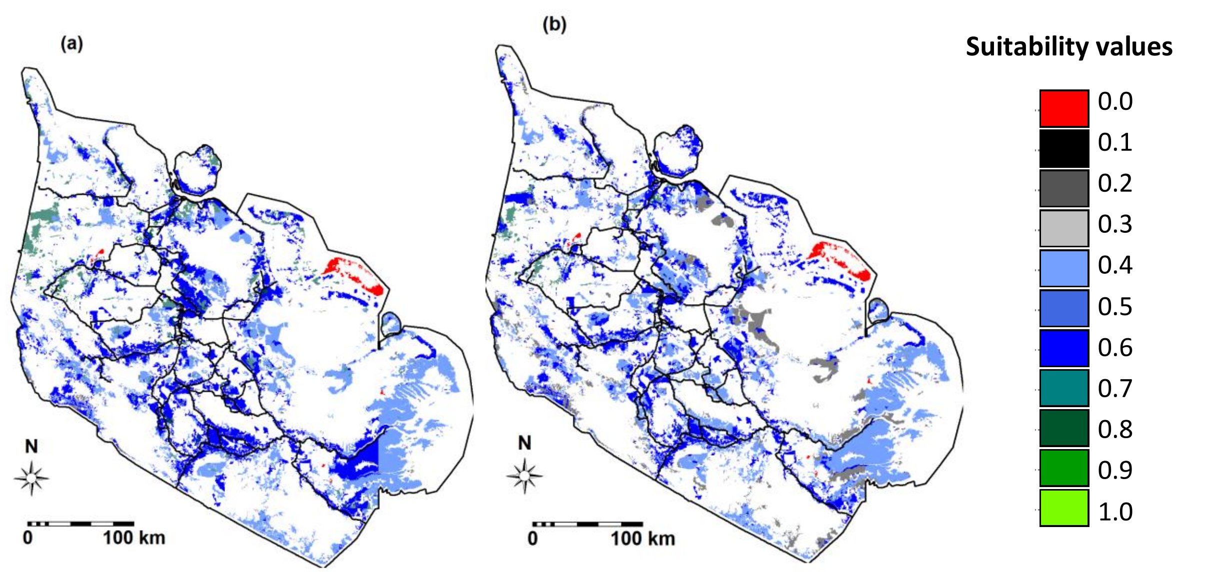
Figure 17: Suitability maps from the conservation and oil palm growers' visions

3.11. Spatial distribution of suitability levels

To identify the spatial distribution of all the suitability levels as ranked by stakeholders, maps shown in figures 18 and 19 were produced. These were derived from crossing suitability maps with a land cover map with potential land units for oil palm expansion.

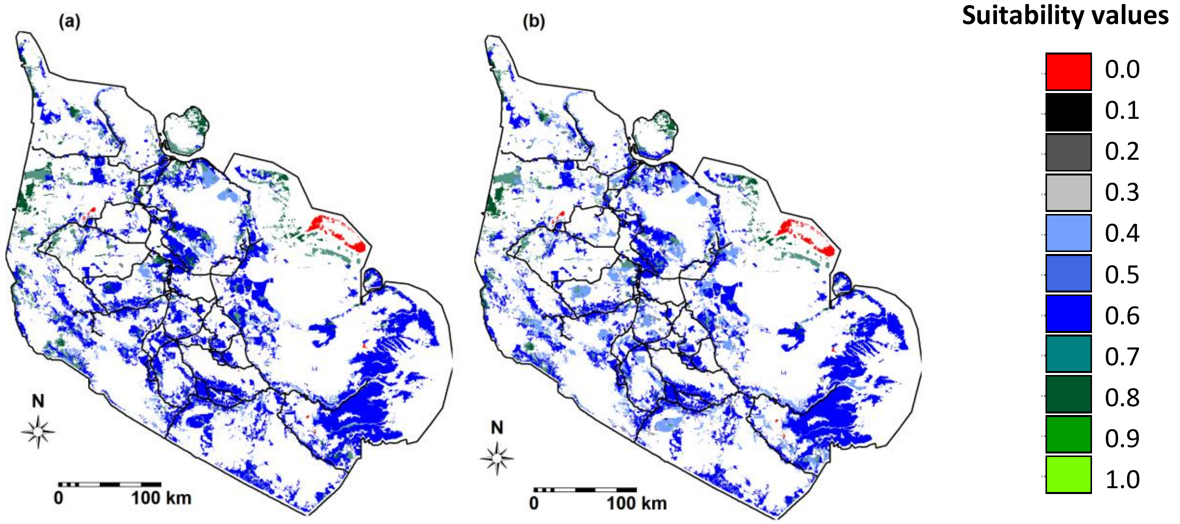


The overall vision: (a) primary perspective and (b) equal weight perspective

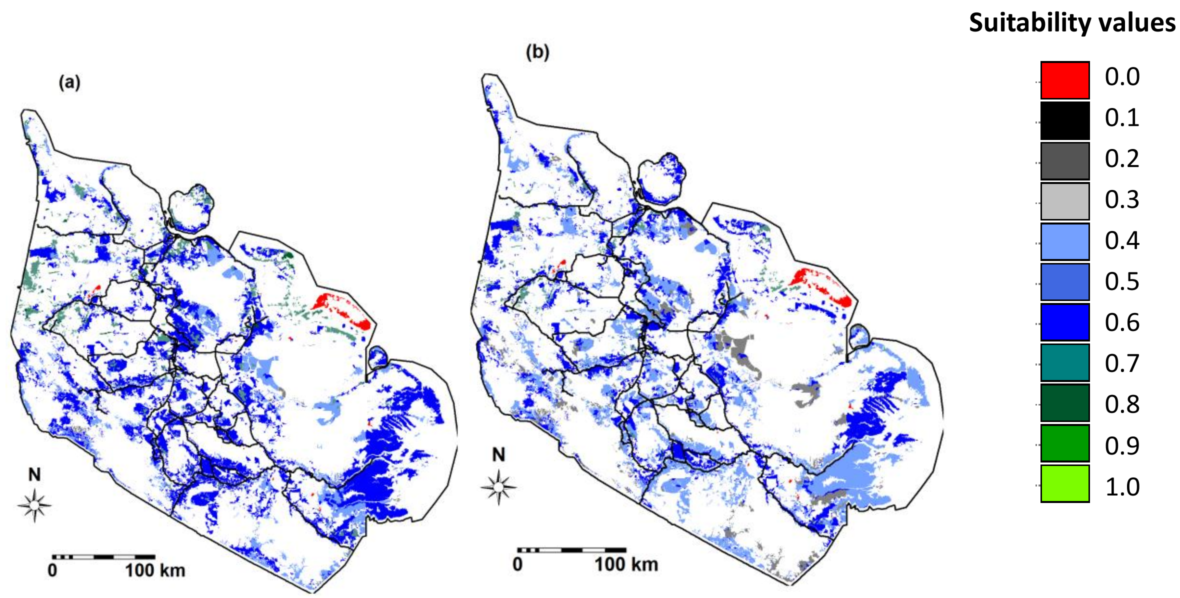


Government stakeholders: (a) primary perspective and (b) equal weight perspective

Figure 18: Average suitability maps for the overall and government visions



conservation stakeholders: (a) primary perspective and (b) equal weight perspective



Oil palm growers: (a) primary perspective and (b) equal weight perspective

Figure 19: Average suitability maps for conservation and oil palm growers' vision

3.12. Results from comparing average rankings for all groups

To identify the difference in opinion among stakeholders regarding criteria ranking, the average suitability ranks were compared (Figure 20).

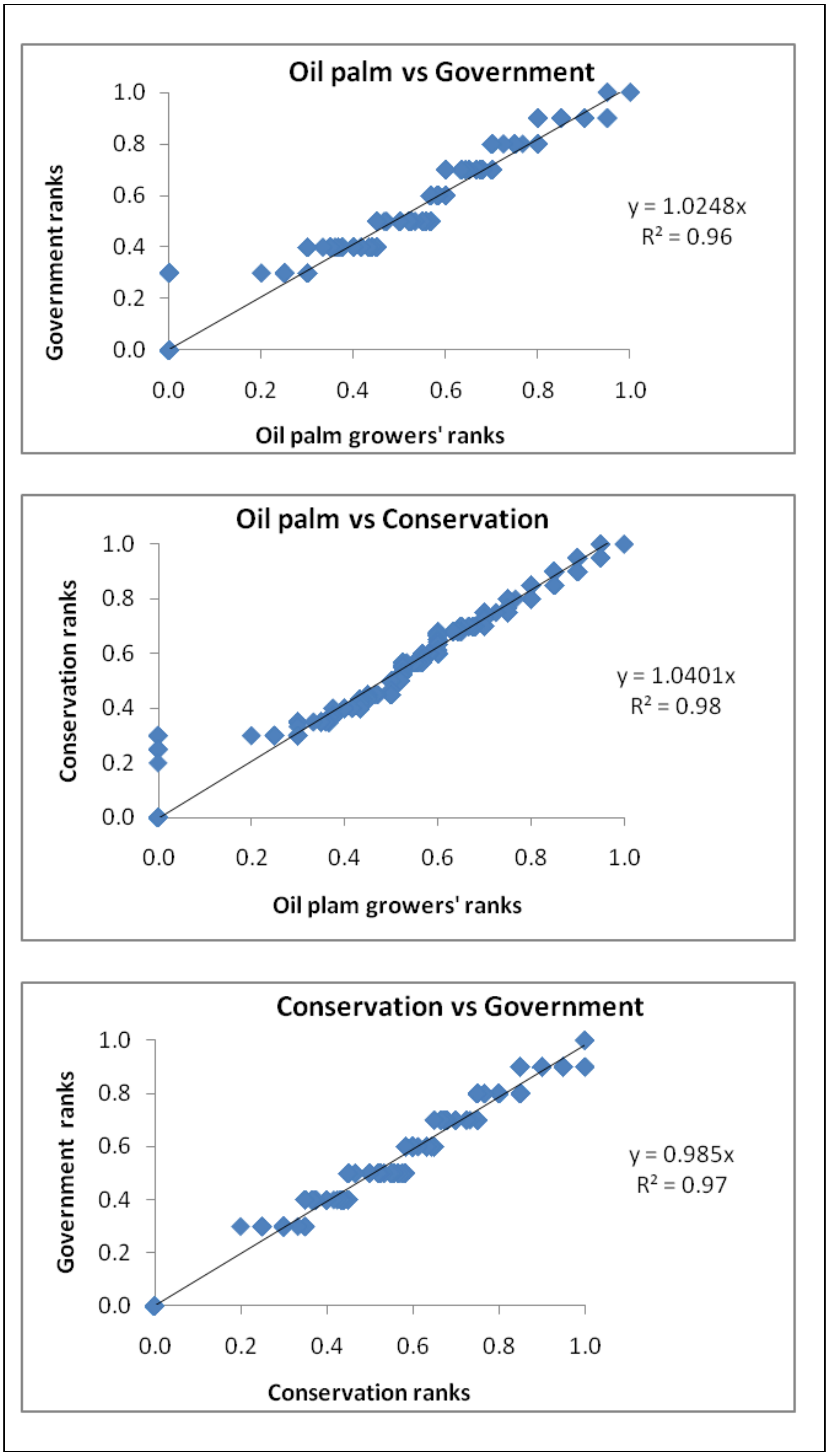


Figure 20: Suitability ranking of stakeholder groups

3.13. Agreement and conflict areas for oil palm expansion

To identify areas that could be used for further oil palm expansion with no conflicts as well as disagreement areas that need much attention from decision makers, figures 21 and 22 for both perspectives were produced.

Conflict and agreement areas in suitability ranking from the primary perspective

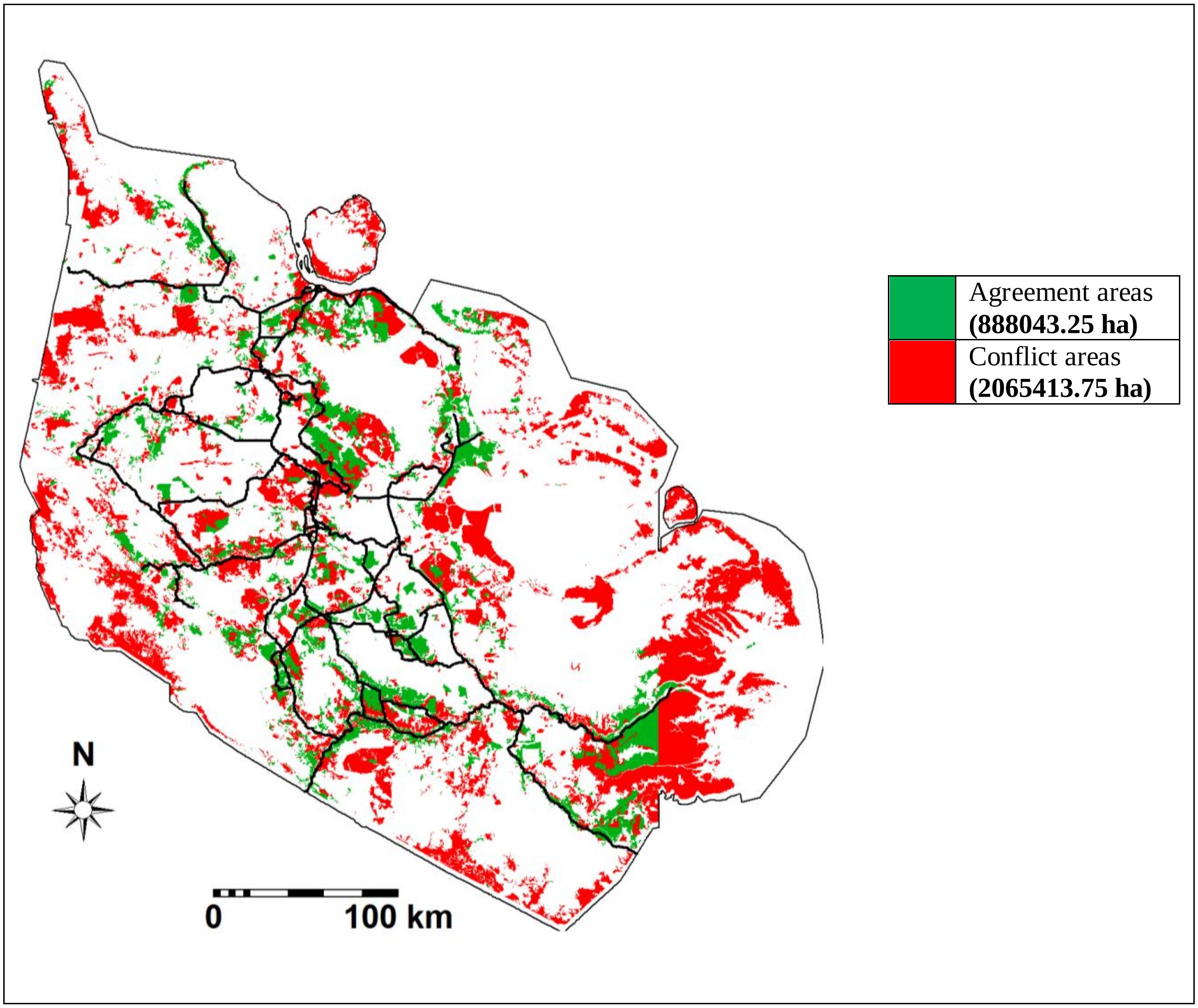


Figure 21: Agreement and disagreement areas from the primary perspective

Conflict and agreement areas in suitability ranking from the equal weight perspective

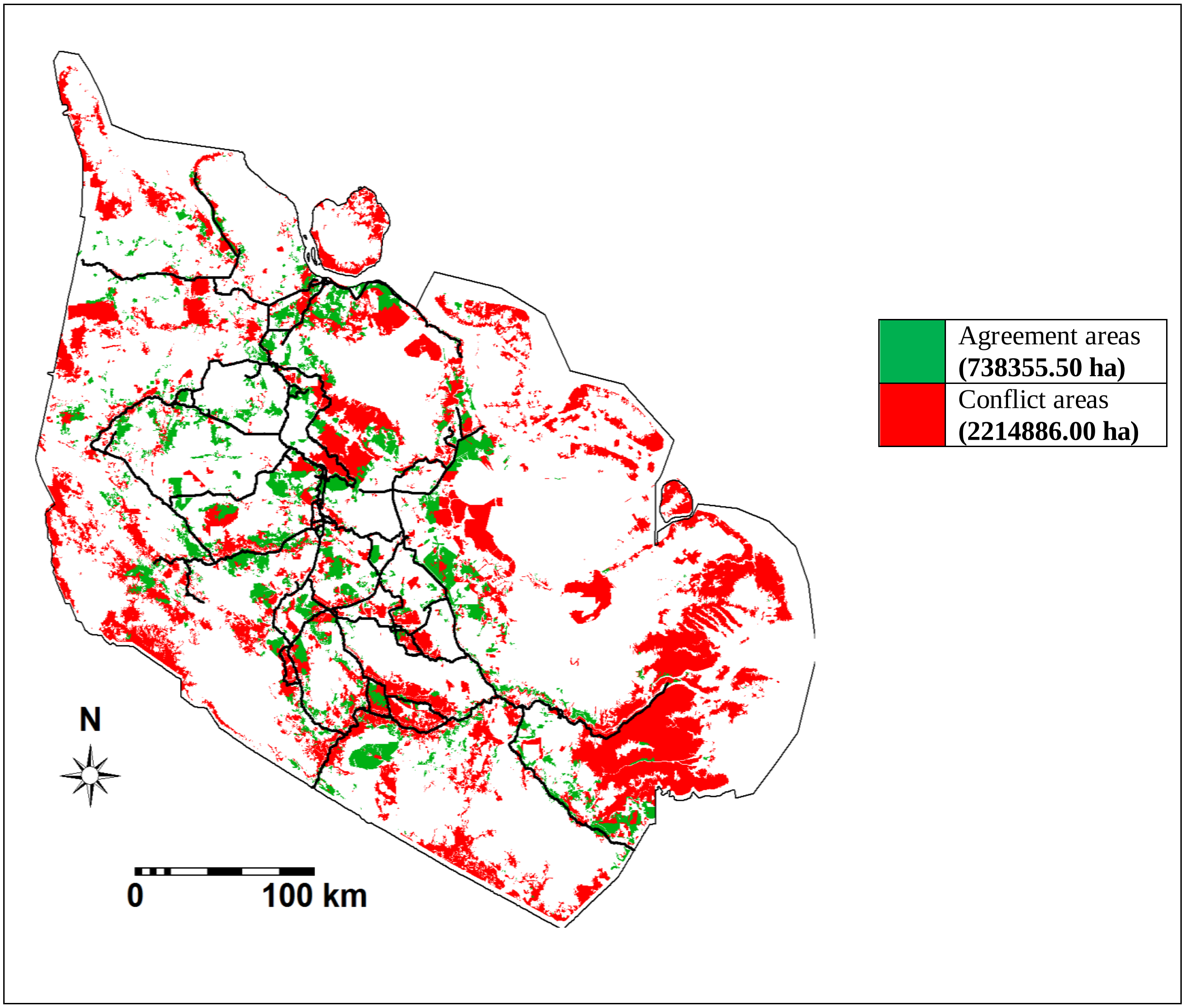


Figure 22: Agreement and disagreement areas from the equal weight perspective

4. Discussion

There has been several confrontations mainly from conservation and environmental NGOs like WWF Indonesia, Greenpeace; etc, researchers, opinion leaders and the public about the continuous unsustainable expansion of oil palm. It is in this view that I proposed to undertake this research to find out where oil palm can be expanded in a sustainable manner. To do so and to avoid conflicts between different stakeholders, I needed to include the opinions of all stakeholders on what is sustainable and what is not. In this regard, the first step of this research was to develop, implement and test a decision support system for the selection of optimal sites for sustainable oil palm expansion in Riau province. However, within the given time frame, it was realised that this broad objective could not be achieved and was thus narrowed down to the development of a decision support tool using stakeholder opinions. The process incorporated GIS and spatial multi criteria approach to design this decision support tool.

A spatial multi criteria evaluation was performed to map the suitability of the various land units according to visions of all the stakeholder groups. Raster map analyses were used since they allow a more accurate representation and modeling of environmental and land use features compared to vector representation (Geneletti and van Duren, 2008). A 30m grid size was selected, since that was the biggest resolution ILWIS could accommodate based on the size of the study area. The study area was divided into 3 portions in order to enable ILWIS analyze the decision problem. The decision problem was decomposed into objectives, aspects, criteria and finally attributes (figure 6). The eight produced raster suitability maps (Figure 16 and 17), were aggregated into the identified land unit polygons, by assigning a suitability value to each unit. I aggregated the pixel values into the land cover units using the average function in ILWIS. The results of this analysis showed the (potentially) conflict locations in the study area. A decision support tool was developed which can be used in analyzing where oil palm expansion can take place while avoiding environmental problems. This tool enables transparent communication between oil palm stakeholders on which areas can potentially be used for further oil palm expansion.

Generally, the study aimed at involving as many stakeholders as possible to fully incorporate local expert knowledge in oil palm site selection (Table 9). However, some stakeholders especially producers did not express themselves yet they are some of the main actors in the oil palm sector (Table 9). Because of this reason, it was not possible to get the opinions of oil palm producers on what criteria they think are relevant for oil palm expansion. Their views together with the rest of other stakeholders with no specified group were analysed under the overall vision. To motivate the participation of these actors in solving the oil palm crisis, RSPO and the government could establish incentives to boost their involvement in such studies. Incorporating the views of all stakeholders in identifying optimal sites for sustainable oil palm expansion will minimise conflicts given the predicted future palm oil demand by (Koh et al., 2009).

In this study, over 50% of the respondents did not answer a part of the questionnaire (Appendix 1). However, (Tsikriktsis, 2005) suggests that many reasons can lead to missing data. For example; it may be due to procedural factors such as errors in data entry of which in this study it is ruled out since I used survey monkey software which directly codes all the provided answers. It may also be due to failure to complete the entire questionnaire (Tsikriktsis, 2005). This was the case especially for the economic criteria like distance to markets, existing oil palm plantations and proximity to the main roads. The sub-group mean substitution method where the missing value is replaced by the mean on the subgroup of which the respondent is a member (Ford, 1976) was used to handle missing data. The subgroup method was preferred most since the study involved different stakeholder groups.

In the survey, stakeholders were asked to specify the land cover types potential and for oil palm expansion (Appendix 1). Results showed that they all selected the same land cover types as shown in figure 8. They also chose the same land cover types for non- suitable areas (Figure 9). However when asked whether they would consider forest areas like; degraded/open mangrove forests, dense mangrove, degraded/open dry land forest, and dense dry land forest, for oil palm conversion, results showed that the overall vision and government stakeholders agreed that degraded/open dry land forests are potential land for oil palm expansion (Appendix 1). This shows how a decision support tool can improve communication between stakeholders and decision makers.

The W values calculated to determine agreement among raters; showed that there was agreement in ranking most criteria especially physical terrain related aspects and land use/ecology aspect (Table 13). This is because they had the highest concordance values. It was not significant in most economic criteria (distance to markets, main roads, and oil palm plantations). However, since (Siegel and Castellan, 1988) suggests that a high W or significant value of W does not mean that the orderings observed are correct, in this study the average rankings were calculated to determine the best measure of "true rankings" (Appendix 2). Low average values represented the most preferred variables. For example for the elevation criterion, low altitudes were preferred (Appendix 2).

From the value functions developed for each vision (Figure 10 to 13), it was observed that for land use and ecology criteria the desirability of selecting an area for palm oil production purpose increased as the distance to this location increased. For the physical criteria like elevation and slope steepness the desirability to select these areas increased when distance to these locations decreased. This shows that higher altitudes and terrains are least preferred for oil palm production as suggested by (Mantel. et al., 2007), since they increase production costs, causes soil erosion and leads to accessibility problems. For some economic criteria like distance to oil palm plantations and main roads, the desirability increased too as distance to their areas decreased. However, there was no clear pattern for some economic criteria especially distance to markets as some stakeholders preferred average distance and others seemed not to mind. This criterion was developed based on the assumption that in every settlement there was a market place. However basing on the results, this criterion does not seem to have much influence in the oil palm site selection process. Selecting the most fitting curve for such a criterion to represent the opinions of stakeholders with minimal subjectivity was a bit challenging. However, the best fitting curves were chosen to fairly represent stakeholder preferences (Figure 10 to 13).

For criteria weighting, the rank sum method according to (Malczewski, 1999) was used. This is because (Malczewski, 1999; Stillwell et al., 1981) "have demonstrated empirically that in many decision situations, the rank order approximations provide a satisfactory approach to weight assessment". Basing on derived criteria ranks (Tables 22 to 25) and weights (Table 26), it can be said that oil palm stakeholders have the same expectations when it comes to selecting suitable areas for sustainable oil palm production. The difference between the stakeholder visions is about their preference as the most and least important criteria for oil palm site selection. For example; government stakeholders gave more weights to water sources where as the rest gave high conservation value forests higher weights (Table 26). However, there was high regard for land use and ecology criteria especially from the overall vision, conservationists and oil palm growers compared to economic aspects since they were ranked as the least important for sustainable oil palm expansion.

After all the criteria maps were converted to partial suitability, standardized to the same value range, assigned their corresponding relative important weights, suitability maps for each vision were developed (Figures 16 and 17). Since managers cannot use pixels (Geneletti and van Duren, 2008), the spatial distribution of suitability values for potential land units were identified (Figure 18 and 19). Most land units had suitability values ranging from 0.4 to 0.6 (Figure 18 and 19). These maps give stakeholders an opportunity to visualize their opinions spatially. Since government has the power to make decisions, this information will support them in formulating a spatial planning policy that will reduce further expansion of oil palm plantations to unsuitable areas with minimal conflicts.

To determine the extent of agreement between the stakeholder visions, the average aggregation method was used. I selected the average method because it is the most commonly used (Geneletti and van Duren, 2008). The results showed that there was high agreement in ranking land units (Figure 20). However, it was higher between oil palm growers and conservationists (Figure 20). The suitability values scattered along the trend line show a high level of agreement and vice versa. Land units with suitability values closer to 0.1 have high potential for oil palm expansion. However, further research needs to be done to identify their suitability levels before any plantations are developed. This clearly explains the difference in opinion on what criteria should be considered most for sustainable oil palm expansion.

A total area of 888043.25 hectares of land was identified as areas agreed upon by all stakeholders from the primary perspective. And from the equal weight perspective, 738355.50 hectares were estimated**.** However, the suitability levels of all these areas vary. The total area from both perspectives is very close but could still influence decision making. It was noticeable that most of these conflict free areas (Figures 21and 22) are close to the main road implying that distance to the main road criterion seems to have a great impact on potential areas for oil palm expansion. Improved infrastructure could have an influence on land allocated for sustainable oil palm expansion. With this established decision support tool, such decisions would be made very easily with minimal conflicts.

Another important outcome of this study was the identification of conflict areas, which can be used as preliminary analysis to address further surveys and data collection. 2065413.75 hectares from the primary perspective and 2214886.00 hectares from the equal weight perspective were estimated (Figure 21 and 22). Conflict areas deserve special attention because their allocation for oil palm growing is not straight forward. Although the total area estimated from both perspectives is almost close, it still shows that a change in weights can influence decision making to some extent. In this case it is up to the government decision makers to decide which areas need more attention.

The study also found out that, there are still some oil palm growers who are still not members of RSPO meaning that their plantations are not certified yet (Appendix 1). Although this was not part of the study, this proves once again that this spatial decision support tool could be used to properly monitor all oil palm plantations hence avoiding environmental problems. The developed decision support system could also be used by financial institutions as a criterion to monitor sustainably managed plantations since they finance most of them. This would enhance proper sustainable oil palm expansion using this scientifically sound method without spending a lot of time and money since this system can be updated anytime.

Finally, since according to (Mantel. et al., 2007), oil palm strives in any soil type as long as water is available, irrigation could be an alternative especially for potential land units that are far from water sources.

5. Conclusion

According to the applied method to determine suitable areas for sustainable oil palm expansion, I conclude that this is a convenient approach since it allowed oil palm stakeholders to get involved directly in identifying what criteria are relevant for oil palm site selection. This study tried to improve the situation which is normally dominated by government decision makers by incorporating the input of local experts in decision making.

A decision support tool was developed capable of analyzing where oil palm expansion can take place while avoiding environmental problems. It also allowed the author to evaluate the views of different actors regarding oil palm expansion using a scientifically sound method.

Through this study I aimed at providing government decision makers with information that can help them in designing an oil palm spatial planning policy. Though the outcomes are rather premature, I believe the approach itself could be interesting for other oil palm growing areas where there is need to identify suitable areas for oil palm expansion or any other crop.

6. Recommendations

- The selection of sites for sustainable oil palm expansion, the scoring of data on any (adopted scale), to permit their integration, should be done by stakeholders involved in the decision making process. By involving all important stakeholders in every step of the process precise results can be improved. Furthermore, involving all stakeholders in every step will minimise the errors due to incorrect selection of objectives, criteria, criteria weights, decision rules and ranking. Then the remaining possible sources of errors would be: positional error and recent of data.
- For better and more reliable results, it is good to further research this issue while incorporating other criteria left out in this study. Soil structure, precipitation, economic viability, proximity to oil palm mills, etc. are some of the factors that can be considered for future study.
- More so, looking at the decision problem from different stakeholder views will lead to more accurate results and reduce conflict of interests. For example in this study only 5 oil palm growers fully participated in the survey. Further research should aim at involving all the main stakeholders in the oil palm sector since they were not fairly represented in this study. This will help in identifying reasons why they did not participate in this study yet they were contacted on time.
- Tests of consistency as recommended by (Beinat, 1997) should be carried out in order to confirm the validity of interpolated curves as preference representation. These checks are especially useful when the curves are based on only few points and curve selection or parameter estimation: the case in this study.
- Non-spatial criteria could also be studies to determine their influence in identifying suitable areas for oil palm site selection. The results from this study could support the government in designing a comprehensive spatial planning policy for sustainable oil palm expansion with minimal conflicts.

- Accuracy assessment of spatial data is recommended to assess the type of information provided, to make sure that there are no inconsistencies. In this study it was not possible since no fieldwork was carried out.

- Sensitivity analysis could also be carried out to identify the effect of different scores on the shape of value function curves before these results are implemented.

- Finally, a better method for determining the average suitability of each land units could be further studied as suggested by (Geneletti and van Duren, 2008).

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Appendix 1: Questionnaire and results

All oil palm stakeholders (overall vision)

Q1. What type of organization, do you work for?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Private Company	24	21.4	21.4	21.4
	Government	35	31.2	31.2	52.7
	Institution/University	28	25.0	25.0	77.7
	Non Government Organization (NGO)	23	20.5	20.5	98.2
	Other	2	1.8	1.8	100.0
	Total	112	100.0	100.0	

Q2. Which field are you working in?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Spatial planning	15	13.4	13.4	13.4
	Environment	35	31.2	31.2	44.6
	Forestry	10	8.9	8.9	53.6
	Wetlands	1	.9	.9	54.5
	Human resource	2	1.8	1.8	56.2
	Education	10	8.9	8.9	65.2
	Other	39	34.8	34.8	100.0
	Total	112	100.0	100.0	

Q3. What is your role in your organization?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Oil Palm Grower	10	8.9	8.9	8.9
	Researcher	31	27.7	27.7	36.6
	Planner	14	12.5	12.5	49.1
	GIS specialist	9	8.0	8.0	57.1
	Public Relations Officer	2	1.8	1.8	58.9
	Lecturer / Teacher	12	10.7	10.7	69.6
	Other	34	30.4	30.4	100.0
	Total	112	100.0	100.0	

Q4. If you are an oil palm grower, is your company / plantation a member of the Roundtable on Sustainable Palm Oil production (RSPO)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	YES	19	17.0	59.4	59.4
	NO	13	11.6	40.6	100.0
	Total	32	28.6	100.0	
Missing	System	80	71.4		
Total		112	100.0		

Q5. Slope steepness (Lereng kecuraman) determines accessibility as well as soil erosion risk. Which of the following slope classes are suitable for oil palm growing? Please rank them in order of suitability.

0 – 0.5

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Suitable	39	34.8	73.6	73.6
	Suitable	11	9.8	20.8	94.3
	Moderately Suitable	2	1.8	3.8	98.1
	Not Suitable	1	.9	1.9	100.0
	Total	53	47.3	100.0	
Missing	System	59	52.7		
Total		112	100.0		

0.5 – 2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Suitable	31	27.7	57.4	57.4
	Suitable	22	19.6	40.7	98.1
	Moderately Suitable	1	.9	1.9	100.0
	Total	54	48.2	100.0	
Missing	System	58	51.8		
Total		112	100.0		

2 – 5

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Suitable	13	11.6	24.1	24.1
	Suitable	28	25.0	51.9	75.9
	Moderately Suitable	12	10.7	22.2	98.1
	Not Suitable	1	.9	1.9	100.0
	Total	54	48.2	100.0	
Missing	System	58	51.8		
Total		112	100.0		

5 – 10

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Suitable	9	8.0	16.4	16.4
	Suitable	20	17.9	36.4	52.7
	Moderately Suitable	19	17.0	34.5	87.3
	Not Suitable	7	6.2	12.7	100.0
	Total	55	49.1	100.0	
Missing	System	57	50.9		
Total		112	100.0		

10 – 15

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Suitable	2	1.8	3.8	3.8
	Suitable	13	11.6	24.5	28.3
	Moderately Suitable	25	22.3	47.2	75.5
	Not Suitability	13	11.6	24.5	100.0
	Total	53	47.3	100.0	
Missing	System	59	52.7		
Total		112	100.0		

15 – 30

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Suitable	1	.9	1.9	1.9
	Suitable	3	2.7	5.6	7.4
	Moderately Suitable	19	17.0	35.2	42.6
	Not Suitable	31	27.7	57.4	100.0
	Total	54	48.2	100.0	
Missing	System	58	51.8		
Total		112	100.0		

30 – 45

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Suitable	1	.9	1.9	1.9
	Suitable	1	.9	1.9	3.7
	Moderately Suitable	4	3.6	7.4	11.1
	Not Suitable	48	42.9	88.9	100.0
	Total	54	48.2	100.0	
Missing	System	58	51.8		
Total		112	100.0		

45>

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Suitable	1	.9	1.9	1.9
	Not Suitable	53	47.3	98.1	100.0
	Total	54	48.2	100.0	
Missing	System	58	51.8		
Total		112	100.0		

Q6. Elevation (Ketinggian) also favours oil palm production in terms of accessibility. Which of the following elevation classes are suitable for oil palm growing? Please rank them in order of suitability.

100 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Suitable	44	39.3	75.9	75.9
	Suitable	11	9.8	19.0	94.8
	Moderately Suitable	1	.9	1.7	96.6
	Not Suitable	2	1.8	3.4	100.0
	Total	58	51.8	100.0	
Missing	System	54	48.2		
Total		112	100.0		

200 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Suitable	16	14.3	28.6	28.6
	Suitable	35	31.2	62.5	91.1
	Moderately Suitable	4	3.6	7.1	98.2
	Not Suitable	1	.9	1.8	100.0
	Total	56	50.0	100.0	
Missing	System	56	50.0		
Total		112	100.0		

500 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Suitable	16	14.3	29.6	29.6
	Moderately Suitable	33	29.5	61.1	90.7
	Not Suitable	5	4.5	9.3	100.0
	Total	54	48.2	100.0	
Missing	System	58	51.8		
Total		112	100.0		

1000 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Suitable	2	1.8	3.6	3.6
	Suitable	1	.9	1.8	5.5
	Moderately Suitable	8	7.1	14.5	20.0
	Not Suitable	44	39.3	80.0	100.0
	Total	55	49.1	100.0	
Missing	System	57	50.9		
Total		112	100.0		

> 2000 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Moderately Suitable	3	2.7	5.7	5.7
	Not Suitable	50	44.6	94.3	100.0
	Total	53	47.3	100.0	
Missing	System	59	52.7		
Total		112	100.0		

Q7. The Roundtable on sustainable Oil Palm Production (RSPO) prescribes that use of fire in the preparation of new plantings should be avoided. Now, imagine the following situation: A forest area was burnt on purpose. Now it is a degraded forest. Would you consider it acceptable to be planted with oil palm?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	YES	10	8.9	16.1	16.1
	NO	52	46.4	83.9	100.0
	Total	62	55.4	100.0	
Missing	System	50	44.6		
Total		112	100.0		

Q8. To what extent, do you think we should consider the forest areas listed below for conversion? Please rank them in order of importance.

Degraded/open mangrove forest

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	8	7.1	12.5	12.5
	Good	4	3.6	6.2	18.8
	Acceptable	9	8.0	14.1	32.8
	Not Acceptable	43	38.4	67.2	100.0
	Total	64	57.1	100.0	
Missing	System	48	42.9		
Total		112	100.0		

Dense mangrove

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	8	7.1	12.3	12.3
	Good	2	1.8	3.1	15.4
	Acceptable	3	2.7	4.6	20.0
	Not Acceptable	52	46.4	80.0	100.0
	Total	65	58.0	100.0	
Missing	System	47	42.0		
Total		112	100.0		

Degraded/open dry land forest

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	7	6.2	10.6	10.6
	Good	17	15.2	25.8	36.4
	Acceptable	26	23.2	39.4	75.8
	Not Acceptable	16	14.3	24.2	100.0
	Total	66	58.9	100.0	
Missing	System	46	41.1		
Total		112	100.0		

Dense dry land forest

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	5	4.5	7.6	7.6
	Good	7	6.2	10.6	18.2
	Acceptable	7	6.2	10.6	28.8
	Not Acceptable	47	42.0	71.2	100.0
	Total	66	58.9	100.0	
Missing	System	46	41.1		
Total		112	100.0		

Q9. Please tick the land cover types that you consider NOT suitable for conversion (maximum 5).

Shrubs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	4	3.6	100.0	100.0
Missing	System	108	96.4		
Total		112	100.0		

Peat swamp

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	50	44.6	100.0	100.0
Missing	System	62	55.4		
Total		112	100.0		

Rubber plantation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	10	8.9	100.0	100.0
Missing	System	102	91.1		
Total		112	100.0		

Acacia plantation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	13	11.6	100.0	100.0
Missing	System	99	88.4		
Total		112	100.0		

Forests

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5	50	44.6	100.0	100.0
Missing	System	62	55.4		
Total		112	100.0		

Swamps/ Wetlands

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	6	48	42.9	100.0	100.0
Missing	System	64	57.1		
Total		112	100.0		

Burnt areas

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	7	12	10.7	100.0	100.0
Missing	System	100	89.3		
Total		112	100.0		

Cleared areas

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	8	6	5.4	100.0	100.0
Missing	System	106	94.6		
Total		112	100.0		

Coconut plantation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	9	6	5.4	100.0	100.0
Missing	System	106	94.6		
Total		112	100.0		

Grassland

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	10	8	7.1	100.0	100.0
Missing	System	104	92.9		
Total		112	100.0		

Mangroves

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	11	53	47.3	100.0	100.0
Missing	System	59	52.7		
Total		112	100.0		

Old Palm oil Plantation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	12	3	2.7	100.0	100.0
Missing	System	109	97.3		
Total		112	100.0		

Q11. To avoid the risk of pollution in waterways (perairan), what is an acceptable distance from oil palm plantations to water sources? Please rank them in order of importance.

<10 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	2	1.8	3.8	3.8
	Acceptable	1	.9	1.9	5.8
	Not Acceptable	49	43.8	94.2	100.0
	Total	52	46.4	100.0	
Missing	System	60	53.6		
Total		112	100.0		

20 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Good	3	2.7	5.9	5.9
	Acceptable	3	2.7	5.9	11.8
	Not Acceptable	45	40.2	88.2	100.0
	Total	51	45.5	100.0	
Missing	System	61	54.5		
Total		112	100.0		

50 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	2	1.8	3.8	3.8
	Good	1	.9	1.9	5.8
	Acceptable	18	16.1	34.6	40.4
	Not Acceptable	31	27.7	59.6	100.0
	Total	52	46.4	100.0	
Missing	System	60	53.6		
Total		112	100.0		

100 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	1	.9	2.0	2.0
	Good	15	13.4	29.4	31.4
	Acceptable	15	13.4	29.4	60.8
	Not Acceptable	20	17.9	39.2	100.0
	Total	51	45.5	100.0	
Missing	System	61	54.5		
Total		112	100.0		

200 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	12	10.7	24.0	24.0
	Good	16	14.3	32.0	56.0
	Acceptable	12	10.7	24.0	80.0
	Not Acceptable	10	8.9	20.0	100.0
	Total	50	44.6	100.0	
Missing	System	62	55.4		
Total		112	100.0		

> 500 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	26	23.2	51.0	51.0
	Good	12	10.7	23.5	74.5
	Acceptable	12	10.7	23.5	98.0
	Not Acceptable	1	.9	2.0	100.0
	Total	51	45.5	100.0	
Missing	System	61	54.5		
Total		112	100.0		

Q12. Due to various functions of Swamps /peat land areas (Rawa / lahan gambut daerah) on the environment, these areas are not suitable for sustainable oil palm growing. Besides they may be vulnerable to contamination. What is an acceptable distance from swamps/peat land areas to oil palm plantations? Please rank them in order of importance.

< 10 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	1	.9	1.9	1.9
	Acceptable	1	.9	1.9	3.8
	Not Acceptable	50	44.6	96.2	100.0
	Total	52	46.4	100.0	
Missing	System	60	53.6		
Total		112	100.0		

20 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Good	2	1.8	3.8	3.8
	Acceptable	1	.9	1.9	5.8
	Not Acceptable	49	43.8	94.2	100.0
	Total	52	46.4	100.0	
Missing	System	60	53.6		
Total		112	100.0		

50 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	1	.9	1.9	1.9
	Good	1	.9	1.9	3.8
	Acceptable	14	12.5	26.9	30.8
	Not Acceptable	36	32.1	69.2	100.0
	Total	52	46.4	100.0	
Missing	System	60	53.6		
Total		112	100.0		

100 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Good	12	10.7	23.1	23.1
	Acceptable	13	11.6	25.0	48.1
	Not Acceptable	27	24.1	51.9	100.0
	Total	52	46.4	100.0	
Missing	System	60	53.6		
Total		112	100.0		

200 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	5	4.5	9.6	9.6
	Good	17	15.2	32.7	42.3
	Acceptable	12	10.7	23.1	65.4
	Not Acceptable	18	16.1	34.6	100.0
	Total	52	46.4	100.0	
Missing	System	60	53.6		
Total		112	100.0		

> 500 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	20	17.9	39.2	39.2
	Good	11	9.8	21.6	60.8
	Acceptable	16	14.3	31.4	92.2
	Not Acceptable	4	3.6	7.8	100.0
	Total	51	45.5	100.0	
Missing	System	61	54.5		
Total		112	100.0		

Q13. Some forest areas have been identified as forests with high conservation value (HCV forests). Conversion of these forests is not allowed. What would be an acceptable distance from a HCV forest to establish an oil palm plantation?

< 10 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	2	1.8	3.8	3.8
	Acceptable	1	.9	1.9	5.7
	Not Acceptable	50	44.6	94.3	100.0
	Total	53	47.3	100.0	
Missing	System	59	52.7		
Total		112	100.0		

20 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	2	1.8	3.7	3.7
	Good	2	1.8	3.7	7.4
	Acceptable	2	1.8	3.7	11.1
	Not Acceptable	48	42.9	88.9	100.0
	Total	54	48.2	100.0	
Missing	System	58	51.8		
Total		112	100.0		

50 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	1	.9	1.9	1.9
	Good	1	.9	1.9	3.8
	Acceptable	13	11.6	25.0	28.8
	Not Acceptable	37	33.0	71.2	100.0
	Total	52	46.4	100.0	
Missing	System	60	53.6		
Total		112	100.0		

100 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	2	1.8	3.8	3.8
	Good	9	8.0	17.3	21.2
	Acceptable	13	11.6	25.0	46.2
	Not Acceptable	28	25.0	53.8	100.0
	Total	52	46.4	100.0	
Missing	System	60	53.6		
Total		112	100.0		

200 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	5	4.5	10.0	10.0
	Good	16	14.3	32.0	42.0
	Acceptable	5	4.5	10.0	52.0
	Not Acceptable	24	21.4	48.0	100.0
	Total	50	44.6	100.0	
Missing	System	62	55.4		
Total		112	100.0		

> 500 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	19	17.0	38.8	38.8
	Good	8	7.1	16.3	55.1
	Acceptable	19	17.0	38.8	93.9
	Not Acceptable	3	2.7	6.1	100.0
	Total	49	43.8	100.0	
Missing	System	63	56.2		
Total		112	100.0		

Q14. What would be an acceptable distance from plantations to market places?

< 0.5 (km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	10	8.9	38.5	38.5
	Good	3	2.7	11.5	50.0
	Acceptable	4	3.6	15.4	65.4
	Not Acceptable	9	8.0	34.6	100.0
	Total	26	23.2	100.0	
Missing	System	86	76.8		
Total		112	100.0		

1 (Km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	9	8.0	34.6	34.6
	Good	6	5.4	23.1	57.7
	Acceptable	5	4.5	19.2	76.9
	Not Acceptable	6	5.4	23.1	100.0
	Total	26	23.2	100.0	
Missing	System	86	76.8		
Total		112	100.0		

3 (Km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	5	4.5	18.5	18.5
	Good	7	6.2	25.9	44.4
	Acceptable	14	12.5	51.9	96.3
	Not Acceptable	1	.9	3.7	100.0
	Total	27	24.1	100.0	
Missing	System	85	75.9		
Total		112	100.0		

5 (Km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	2	1.8	7.1	7.1
	Good	11	9.8	39.3	46.4
	Acceptable	10	8.9	35.7	82.1
	Not Acceptable	5	4.5	17.9	100.0
	Total	28	25.0	100.0	
Missing	System	84	75.0		
Total		112	100.0		

> 10 (km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	3	2.7	10.7	10.7
	Good	3	2.7	10.7	21.4
	Acceptable	12	10.7	42.9	64.3
	Not Acceptable	10	8.9	35.7	100.0
	Total	28	25.0	100.0	
Missing	System	84	75.0		
Total		112	100.0		

Q15. What would be an acceptable distance from existing plantations to develop new plantings?

< 100 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	13	11.6	41.9	41.9
	Good	7	6.2	22.6	64.5
	Acceptable	6	5.4	19.4	83.9
	Not Acceptable	5	4.5	16.1	100.0
	Total	31	27.7	100.0	
Missing	System	81	72.3		
Total		112	100.0		

500 (m)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	12	10.7	37.5	37.5
	Good	8	7.1	25.0	62.5
	Acceptable	9	8.0	28.1	90.6
	Not Acceptable	3	2.7	9.4	100.0
	Total	32	28.6	100.0	
Missing	System	80	71.4		
Total		112	100.0		

1 (Km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	4	3.6	12.1	12.1
	Good	15	13.4	45.5	57.6
	Acceptable	13	11.6	39.4	97.0
	Not Acceptable	1	.9	3.0	100.0
	Total	33	29.5	100.0	
Missing	System	79	70.5		
Total		112	100.0		

5 (Km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	2	1.8	6.1	6.1
	Good	8	7.1	24.2	30.3
	Acceptable	20	17.9	60.6	90.9
	Not Acceptable	3	2.7	9.1	100.0
	Total	33	29.5	100.0	
Missing	System	79	70.5		
Total		112	100.0		

> 10 (Km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	1	.9	3.1	3.1
	Good	1	.9	3.1	6.2
	Acceptable	17	15.2	53.1	59.4
	Not Acceptable	13	11.6	40.6	100.0
	Total	32	28.6	100.0	
Missing	System	80	71.4		
Total		112	100.0		

Q16. Accessibility (Aksesibilitas) for trucks is another factor that facilitates palm oil production especially during the harvesting period. What is an acceptable distance from oil palm plantations to the nearest main road? Please rank them in order of importance.

< 0.5 (km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	22	19.6	53.7	53.7
	Good	9	8.0	22.0	75.6
	Acceptable	4	3.6	9.8	85.4
	Not Acceptable	6	5.4	14.6	100.0
	Total	41	36.6	100.0	
Missing	System	71	63.4		
Total		112	100.0		

1.0 (km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	16	14.3	38.1	38.1
	Good	16	14.3	38.1	76.2
	Acceptable	7	6.2	16.7	92.9
	Not Acceptable	3	2.7	7.1	100.0
	Total	42	37.5	100.0	
Missing	System	70	62.5		
Total		112	100.0		

1.5 (km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	8	7.1	19.0	19.0
	Good	22	19.6	52.4	71.4
	Acceptable	9	8.0	21.4	92.9
	Not Acceptable	3	2.7	7.1	100.0
	Total	42	37.5	100.0	
Missing	System	70	62.5		
Total		112	100.0		

2.0 (km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	4	3.6	9.8	9.8
	Good	16	14.3	39.0	48.8
	Acceptable	17	15.2	41.5	90.2
	Not Acceptable	4	3.6	9.8	100.0
	Total	41	36.6	100.0	
Missing	System	71	63.4		
Total		112	100.0		

3.0 (km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	2	1.8	5.0	5.0
	Good	11	9.8	27.5	32.5
	Acceptable	20	17.9	50.0	82.5
	Not Acceptable	7	6.2	17.5	100.0
	Total	40	35.7	100.0	
Missing	System	72	64.3		
Total		112	100.0		

> 5.0 (km)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Good	2	1.8	4.5	4.5
	Good	5	4.5	11.4	15.9
	Acceptable	16	14.3	36.4	52.3
	Not Acceptable	21	18.8	47.7	100.0
	Total	44	39.3	100.0	
Missing	System	68	60.7		
Total		112	100.0		

Appendix 2: Average rankings of all the criteria according to different stakeholder groups

Criteria	Overall vision	Conservation	Government	Oil palm growers
	Rank average			
Physical terrain related aspects				
Slope steepness				
0 – 0.5	2.055	1.676	2.600	1.600
0.5 – 2	2.082	2.059	2.033	1.900
2 – 5	2.982	3.118	2.733	3.000
5 – 10	3.955	4.441	3.500	4.500
10 – 15	4.982	5.265	4.767	5.500
15 – 30	6.100	6.059	6.067	6.300
30 – 45	6.827	6.529	7.067	6.600
>45	7.018	6.735	7.233	6.600
Elevation				
<100	1.388	1.500	1.406	1.100
200	1.879	2.026	1.875	2.000
500	3.017	2.947	3.031	2.900
1000	4.181	4.158	4.094	4.500
>2000	4.534	4.368	4.594	4.500
Land use and Ecological aspect				
Distance to water sources				
<10	4.856	4.650	4.808	5.700
20	4.712	4.725	4.808	5.200
50	4.192	4.375	4.115	3.700
100	3.433	3.525	3.385	2.900
200	2.356	2.400	2.269	1.900
>500	1.452	1.275	1.615	1.600
Distance to peat/swamps				
<10	4.585	4.400	4.654	5.500
20	4.566	4.475	4.500	5.300
50	4.170	4.225	3.846	4.000
100	3.528	3.450	3.423	3.000
200	2.755	3.125	2.846	2.100
>500	1.396	1.325	1.731	1.100
Distance to HCVF				
<10	4.500	4.450	4.538	5.100

20	4.425	4.525	4.385	4.800
50	4.151	4.225	3.923	4.200
100	3.500	3.475	3.462	2.900
200	3.038	2.975	3.115	2.300
>500	1.387	1.350	1.577	1.700
Economic aspects				
Distance to markets				
<500	2.926	2.500	3.200	3.000
1000	2.519	2.643	2.500	3.000
3000	2.630	2.714	2.650	3.167
5000	3.148	3.571	2.950	2.833
>10000	3.778	3.571	3.700	3.000
Distance to oil palm concessions				
<100	2.409	2.056	2.350	2.500
500	2.394	2.556	1.850	2.700
1000	2.712	2.722	2.800	2.800
5000	3.333	3.278	3.450	3.300
>10000	4.152	4.389	4.550	3.700
Distance to the main road				
<500	2.407	1.929	2.625	2.400
1000	2.523	2.500	2.625	2.600
1500	3.023	2.714	3.167	3.500
2000	3.651	4.107	3.417	3.500
3000	4.233	4.393	4.292	3.900
>5000	5.163	5.357	4.875	5.100

Appendix 3: ILWIS scripts used to standardize source maps

All stakeholders

- DEM_BR_A=min(1,max(0,-0.000000000107611*POW(DEM_BR.mpr,3)+0.0000007918972488*POW(DEM_BR.mpr,2)-0.001735208487755*DEM_BR.mpr+1.163534804928140))
- DEM_BL_A=min(1,max(0,-0.000000000107611*POW(DEM_BL.mpr,3)+0.0000007918972488*POW(DEM_BL.mpr,2)-0.001735208487755*DEM_BL.mpr+1.163534804928140))
- DEM_TOP_A=min(1,max(0,-0.000000000107611*POW(DEM_TOP.mpr,3)+0.0000007918972488*POW(DEM_TOP.mpr,2)-0.001735208487755*DEM_TOP.mpr+1.163534804928140))

• WATER_BR_A=min(1,max(0,0.00000000386374*POW(WATER_BR_DIST.mpr,3)-0.000008900315599*POW(WATER_BR_DIST.mpr,2)+0.005605645316981*WATER_BR_DIST.mpr-0.060717118513326)) • WATER_TOP_A=min(1,max(0,0.00000000386374*POW(WATER_TOP_DIST.mpr,3)-0.000008900315599*POW(WATER_TOP_DIST.mpr,2)+0.005605645316981*WATER_TOP_DIST.mpr-0.060717118513326)) • WATER_BL_A=min(1,max(0,0.00000000386374*POW(WATER_BL_DIST.mpr,3)-0.000008900315599*POW(WATER_BL_DIST.mpr,2)+0.005605645316981*WATER_BL_DIST.mpr-0.060717118513326))
• PEAT_BL_A=min(1,max(0,0.000000006151731*POW(PEAT_BL_DIST.mpr,3)-0.000007905812365*POW(PEAT_BL_DIST.mpr,2)+0.004543456010214*PEAT_BL_DIST.mpr-0.064424019125892)) • PEAT_TOP_A=min(1,max(0,0.000000006151731*POW(PEAT_TOP_DIST.mpr,3)-0.000007905812365*POW(PEAT_TOP_DIST.mpr,2)+0.004543456010214*PEAT_TOP_DIST.mpr-0.064424019125892)) • PEAT_BR_A=min(1,max(0,0.000000006151731*POW(PEAT_BR_DIST.mpr,3)-0.000007905812365*POW(PEAT_BR_DIST.mpr,2)+0.004543456010214*PEAT_BR_DIST.mpr-0.064424019125892))
• MARKET_BR_A=min(1,max(0,-0.000000008821755*POW(SETTLE_BR_DIST.mpr,2)+0.000000814909669*SETTLE_BR_DIST.mpr+0.853242214805905)) • MARKET_BL_A=min(1,max(0,-0.000000008821755*POW(SETTLE_BL_DIST.mpr,2)+0.000000814909669*SETTLE_BL_DIST.mpr+0.853242214805905)) • MARKET_TOP_A=min(1,max(0,-0.000000008821755*POW(SETTLE_TOP_DIST.mpr,2)+0.000000814909669*SETTLE_TOP_DIST.mpr+0.853242214805905))
• HCVF_BR_A=iff(HCVF_BR_DIST.mpr>500,1,min(1,max(0,-0.000001565205797*HCVF_BR_DIST.mpr*HCVF_BR_DIST.mpr+0.002779343154457*HCVF_BR_DIST.mpr))) • HCVF_TOP_A=iff(HCVF_TOP_DIST.mpr>500,1,min(1,max(0,-0.000001565205797*HCVF_TOP_DIST.mpr*HCVF_TOP_DIST.mpr+0.002779343154457*HCVF_TOP_DIST.mpr))) • HCVF_BL_A=iff(HCVF_BL_DIST.mpr>500,1,min(1,max(0,-0.000001565205797*HCVF_BL_DIST.mpr*HCVF_BL_DIST.mpr+0.002779343154457*HCVF_BL_DIST.mpr)))
• OILPALM_BL_A=min(1,max(0,0.000000002035710*POW(OIL_PALM_BL_DIST.mpr,2)-0.000120419160410*OIL_PALM_BL_DIST.mpr+1.003675960871290)) • OILPALM_BR_A=min(1,max(0,0.000000002035710*POW(OIL_PALM_BR_DIST.mpr,2)-0.000120419160410*OIL_PALM_BR_DIST.mpr+1.003675960871290)) • OILPALM_TOP_A=min(1,max(0,0.000000002035710*POW(OIL_PALM_TOP_DIST.mpr,2)-0.000120419160410*OIL_PALM_TOP_DIST.mpr+1.003675960871290))
• ROAD_TOP_A=iff(ROAD_TOP_DIST.mpr>5000,0,min(1,max(0,-0.000000007104571*ROAD_TOP_DIST.mpr*ROAD_TOP_DIST.mpr-0.000171049704738*ROAD_TOP_DIST.mpr+1.000000000000000))) • ROAD_BL_A=iff(ROAD_BL_DIST.mpr>5000,0,min(1,max(0,-0.000000007104571*ROAD_BL_DIST.mpr*ROAD_BL_DIST.mpr-0.000171049704738*ROAD_BL_DIST.mpr+1.000000000000000))) • ROAD_BR_A=iff(ROAD_BR_DIST.mpr>5000,0,min(1,max(0,-0.000000007104571*ROAD_BR_DIST.mpr*ROAD_BR_DIST.mpr-0.000171049704738*ROAD_BR_DIST.mpr+1.000000000000000)))

Oil palm growers

• DEM_BL_O=min(1,max(0,0.00000054*DEM_BL.mpr*DEM_BL.mpr-0.00164673*DEM_BL.mpr+1.11602422)) • DEM_BR_O=min(1,max(0,0.00000054*DEM_BR.mpr*DEM_BR.mpr-0.00164673*DEM_BR.mpr+1.11602422)) • DEM_TOP_O=min(1,max(0,0.00000054*DEM_TOP.mpr*DEM_TOP.mpr-0.00164673*DEM_TOP.mpr+1.11602422))
• WATER_BR_O=iff(WATER_BR_DIST.mpr>500,1,min(1,max(0,-0.0000104287*WATER_BR_DIST.mpr*WATER_BR_DIST.mpr+ 0.0071925248*WATER_BR_DIST.mpr))) • WATER_BL_O=iff(WATER_BL_DIST.mpr>500,1,min(1,max(0,-0.0000104287*WATER_BL_DIST.mpr*WATER_BL_DIST.mpr+ 0.0071925248*WATER_BL_DIST.mpr))) • WATER_TOP_O=iff(WATER_TOP_DIST.mpr>500,1,min(1,max(0,-0.0000104287*WATER_TOP_DIST.mpr*WATER_TOP_DIST.mpr+ 0.0071925248*WATER_TOP_DIST.mpr)))
• PEAT_BL_O=iff(PEAT_BL_DIST.mpr>500,1,min(1,max(0,-0.000007333146172*PEAT_BL_DIST.mpr*PEAT_BL_DIST.mpr+0.005653275282189*PEAT_BL_DIST.mpr))) • PEAT_TOP_O=iff(PEAT_TOP_DIST.mpr>500,1,min(1,max(0,-0.000007333146172*PEAT_TOP_DIST.mpr*PEAT_TOP_DIST.mpr+0.005653275282189*PEAT_TOP_DIST.mpr))) • PEAT_BR_O=iff(PEAT_BR_DIST.mpr>500,1,min(1,max(0,-0.000007333146172*PEAT_BR_DIST.mpr*PEAT_BR_DIST.mpr+0.005653275282189*PEAT_BR_DIST.mpr)))
• HCVF_BR_O=iff(HCVF_BR_DIST.mpr>500,1,min(1,max(0,-0.000008168897238*HCVF_BR_DIST.mpr*HCVF_BR_DIST.mpr+0.006073064775174*HCVF_BR_DIST.mpr))) • HCVF_BL_O=iff(HCVF_BL_DIST.mpr>500,1,min(1,max(0,-0.000008168897238*HCVF_BL_DIST.mpr*HCVF_BL_DIST.mpr+0.006073064775174*HCVF_BL_DIST.mpr))) • HCVF_TOP_O=iff(HCVF_TOP_DIST.mpr>500,1,min(1,max(0,-0.000008168897238*HCVF_TOP_DIST.mpr*HCVF_TOP_DIST.mpr+0.006073064775174*HCVF_TOP_DIST.mpr)))
• OIL_PALM_TOP_O=min(1,max(0,0.0000000066*OIL_PALM_TOP_DIST.mpr*OIL_PALM_TOP_DIST.mpr-0.0001602380*OIL_PALM_TOP_DIST.mpr+0.9492035575)) • OIL_PALM_BL_O=min(1,max(0,0.0000000066*OIL_PALM_BL_DIST.mpr*OIL_PALM_BL_DIST.mpr-0.0001602380*OIL_PALM_BL_DIST.mpr+0.9492035575)) • OIL_PALM_BR_O=min(1,max(0,0.0000000066*OIL_PALM_BR_DIST.mpr*OIL_PALM_BR_DIST.mpr-0.0001602380*OIL_PALM_BR_DIST.mpr+0.9492035575))
• ROAD_BL_O=min(1,max(0,-0.000215277777778*ROAD_BL_DIST.mpr+1.059027777777780)) • ROAD_BR_O=min(1,max(0,-0.000215277777778*ROAD_BR_DIST.mpr+1.059027777777780)) • ROAD_TOP_O=min(1,max(0,-0.000215277777778*ROAD_TOP_DIST.mpr+1.059027777777780))
• MARKET_TOP_O=iff(SETTLE_TOP_DIST.mpr>10000,0,min(1,max(0,-0.000000005873398*SETTLE_TOP_DIST.mpr*SETTLE_TOP_DIST.mpr+0.000078930666940*SETTLE_TOP_DIST.mpr+0.351045816223717))) • MARKET_BR_O=iff(SETTLE_BR_DIST.mpr>10000,0,min(1,max(0,-0.000000005873398*SETTLE_BR_DIST.mpr*SETTLE_BR_DIST.mpr+0.000078930666940*SETTLE_BR_DIST.mpr+0.351045816223717))) • MARKET_BL_O=iff(SETTLE_BL_DIST.mpr>10000,0,min(1,max(0,-0.000000005873398*SETTLE_BL_DIST.mpr*SETTLE_BL_DIST.mpr+0.000078930666940*SETTLE_BL_DIST.mpr+0.351045816223717)))

Conservation stakeholders

• DEM_TOP_C=min(1,max(0,0.000000489647573*DEM_TOP.mpr*DEM_TOP.mpr-0.001545920904275*DEM_TOP.mpr+1.132860907898670)) • DEM_BL_C=min(1,max(0,0.000000489647573*DEM_BL.mpr*DEM_BL.mpr-0.001545920904275*DEM_BL.mpr+1.132860907898670)) • DEM_BR_C=min(1,max(0,0.000000489647573*DEM_BR.mpr*DEM_BR.mpr-0.001545920904275*DEM_BR.mpr+1.132860907898670))
• WATER_TOP_C=iff(WATER_TOP_DIST.mpr>500,1,min(1,max(0,-0.000005057612815*WATER_TOP_DIST.mpr*WATER_TOP_DIST.mpr+0.004679397609825*WATER_TOP_DIST.mpr-0.073414279602277))) • WATER_BL_C=iff(WATER_BL_DIST.mpr>500,1,min(1,max(0,-0.000005057612815*WATER_BL_DIST.mpr*WATER_BL_DIST.mpr+0.004679397609825*WATER_BL_DIST.mpr-0.073414279602277))) • WATER_BR_C=iff(WATER_BR_DIST.mpr>500,1,min(1,max(0,-0.000005057612815*WATER_BR_DIST.mpr*WATER_BR_DIST.mpr+0.004679397609825*WATER_BR_DIST.mpr-0.073414279602277)))
• PEAT_BL_C=iff(PEAT_BL_DIST.mpr>500,1,min(1,max(0,-0.000001401907361*PEAT_BL_DIST.mpr*PEAT_BL_DIST.mpr+0.002735657592461*PEAT_BL_DIST.mpr-0.020909648974181))) • PEAT_BR_C=iff(PEAT_BR_DIST.mpr>500,1,min(1,max(0,-0.000001401907361*PEAT_BR_DIST.mpr*PEAT_BR_DIST.mpr+0.002735657592461*PEAT_BR_DIST.mpr-0.020909648974181))) • PEAT_TOP_C=iff(PEAT_TOP_DIST.mpr>500,1,min(1,max(0,-0.000001401907361*PEAT_TOP_DIST.mpr*PEAT_TOP_DIST.mpr+0.002735657592461*PEAT_TOP_DIST.mpr-0.020909648974181)))
• HCVF_TOP_C=iff(HCVF_TOP_DIST.mpr>500,1,min(1,max(0,-0.000002280184847*HCVF_TOP_DIST.mpr*HCVF_TOP_DIST.mpr+0.003197165788329*HCVF_TOP_DIST.mpr-0.030933668530765))) • HCVF_BL_C=iff(HCVF_BL_DIST.mpr>500,1,min(1,max(0,-0.000002280184847*HCVF_BL_DIST.mpr*HCVF_BL_DIST.mpr+0.003197165788329*HCVF_BL_DIST.mpr-0.030933668530765))) • HCVF_BR_C=iff(HCVF_BR_DIST.mpr>500,1,min(1,max(0,-0.000002280184847*HCVF_BR_DIST.mpr*HCVF_BR_DIST.mpr+0.003197165788329*HCVF_BR_DIST.mpr-0.030933668530765)))
• MARKET_TOP_C=iff(SETTLE_TOP_DIST.mpr>5000,0,min(1,max(0,0.000000014411823*SETTLE_TOP_DIST.mpr*SETTLE_TOP_DIST.mpr-0.000264404468852*SETTLE_TOP_DIST.mpr+1.174484218388320))) • MARKET_BL_C=iff(SETTLE_BL_DIST.mpr>5000,0,min(1,max(0,0.000000014411823*SETTLE_BL_DIST.mpr*SETTLE_BL_DIST.mpr-0.000264404468852*SETTLE_BL_DIST.mpr+1.174484218388320))) • MARKET_BR_C=iff(SETTLE_BR_DIST.mpr>5000,0,min(1,max(0,0.000000014411823*SETTLE_BR_DIST.mpr*SETTLE_BR_DIST.mpr-0.000264404468852*SETTLE_BR_DIST.mpr+1.174484218388320)))
• OILPALM_TOP_C=min(1,max(0,0.000000004495009*OIL_PALM_TOP_DIST.mpr*OIL_PALM_TOP_DIST.mpr+0.000143137558269*OIL_PALM_TOP_DIST.mpr+1.000000000000000)) • OILPALM_BR_C=min(1,max(0,0.000000004495009*OIL_PALM_BR_DIST.mpr*OIL_PALM_BR_DIST.mpr+0.000143137558269*OIL_PALM_BR_DIST.mpr+1.000000000000000)) • OILPALM_BL_C=min(1,max(0,0.000000004495009*OIL_PALM_BL_DIST.mpr*OIL_PALM_BL_DIST.mpr+0.000143137558269*OIL_PALM_BL_DIST.mpr+1.000000000000000))

- ROAD_BR_C=min(1,max(0,0.000000009637313*ROAD_BR_DIST.mpr*ROAD_BR_DIST.mpr-0.000253559096116*ROAD_BR_DIST.mpr+1.000000000000000))
- ROAD_BL_C=min(1,max(0,0.000000009637313*ROAD_BL_DIST.mpr*ROAD_BL_DIST.mpr-0.000253559096116*ROAD_BL_DIST.mpr+1.000000000000000))
- ROAD_TOP_C=min(1,max(0,0.000000009637313*ROAD_TOP_DIST.mpr*ROAD_TOP_DIST.mpr-0.000253559096116*ROAD_TOP_DIST.mpr+1.000000000000000))

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- DEM_BL_G=min(1,max(0,-0.000000000173742*POW(DEM_BL.mpr,3)+0.000000950548195*POW(DEM_BL.mpr,2)-0.001791906320812*DEM_BL.mpr+1.171659681399880))
- DEM_TOP_G=min(1,max(0,-0.000000000173742*POW(DEM_TOP.mpr,3)+0.000000950548195*POW(DEM_TOP.mpr,2)-0.001791906320812*DEM_TOP.mpr+1.171659681399880))
- DEM_BR_G=min(1,max(0,-0.000000000173742*POW(DEM_BR.mpr,3)+0.000000950548195*POW(DEM_BR.mpr,2)-0.001791906320812*DEM_BR.mpr+1.171659681399880))

- WATER_BL_G=iff(WATER_BL_DIST.mpr>500,1,min(1,max(0,-0.000006106245154*WATER_BL_DIST.mpr*WATER_BL_DIST.mpr+0.005060867361706*WATER_BL_DIST.mpr)))
- WATER_BR_G=iff(WATER_BR_DIST.mpr>500,1,min(1,max(0,-0.000006106245154*WATER_BR_DIST.mpr*WATER_BR_DIST.mpr+0.005060867361706*WATER_BR_DIST.mpr)))
- WATER_TOP_G=iff(WATER_TOP_DIST.mpr>500,1,min(1,max(0,-0.000006106245154*WATER_TOP_DIST.mpr*WATER_TOP_DIST.mpr+0.005060867361706*WATER_TOP_DIST.mpr)))

- PEAT_TOP_G=iff(PEAT_TOP_DIST.mpr>500,1,min(1,max(0,-0.000004487973328*PEAT_TOP_DIST.mpr*PEAT_TOP_DIST.mpr+0.004233372735010*PEAT_TOP_DIST.mpr)))
- PEAT_BL_G=iff(PEAT_BL_DIST.mpr>500,1,min(1,max(0,-0.000004487973328*PEAT_BL_DIST.mpr*PEAT_BL_DIST.mpr+0.004233372735010*PEAT_BL_DIST.mpr)))
- PEAT_BR_G=iff(PEAT_BR_DIST.mpr>500,1,min(1,max(0,-0.000004487973328*PEAT_BR_DIST.mpr*PEAT_BR_DIST.mpr+0.004233372735010*PEAT_BR_DIST.mpr)))

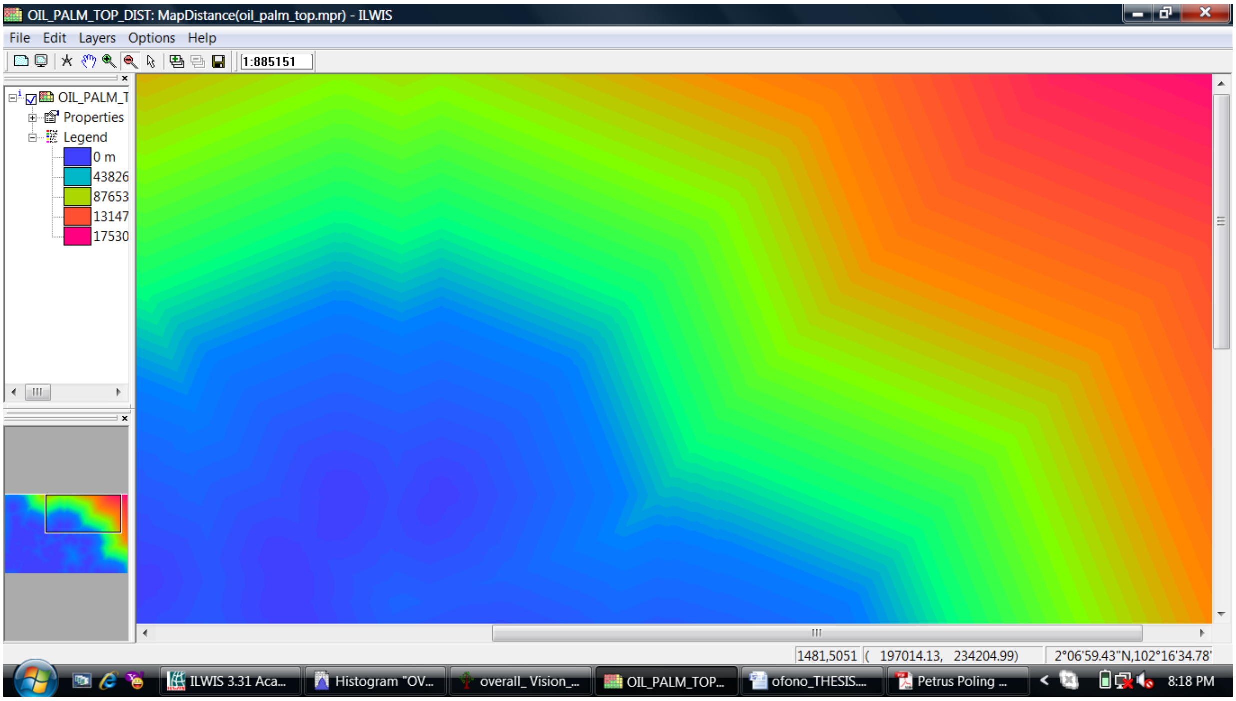
- HCVF_BL_G=iff(HCVF_BL_DIST.mpr>500,1,min(1,max(0,-0.000002410408519*HCVF_BL_DIST.mpr*HCVF_BL_DIST.mpr+0.003192058632773*HCVF_BL_DIST.mpr)))
- HCVF_BR_G=iff(HCVF_BR_DIST.mpr>500,1,min(1,max(0,-0.000002410408519*HCVF_BR_DIST.mpr*HCVF_BR_DIST.mpr+0.003192058632773*HCVF_BR_DIST.mpr)))
- HCVF_TOP_G=iff(HCVF_TOP_DIST.mpr>500,1,min(1,max(0,-0.000002410408519*HCVF_TOP_DIST.mpr*HCVF_TOP_DIST.mpr+0.003192058632773*HCVF_TOP_DIST.mpr)))

- MARKET_BL_G=iff(SETTLE_BL_DIST.mpr>5000,0,min(1,max(0,-0.000000017447555*SETTLE_BL_DIST.mpr*SETTLE_BL_DIST.mpr+0.000109787093290*SETTLE_BL_DIST.mpr+0.627120023765070)))
- MARKET_BR_G=iff(SETTLE_BR_DIST.mpr>5000,0,min(1,max(0,-0.000000017447555*SETTLE_BR_DIST.mpr*SETTLE_BR_DIST.mpr+0.000109787093290*SETTLE_BR_DIST.mpr+0.627120023765070)))
- MARKET_TOP_G=iff(SETTLE_TOP_DIST.mpr>5000,0,min(1,max(0,-0.000000017447555*SETTLE_TOP_DIST.mpr*SETTLE_TOP_DIST.mpr+0.000109787093290*SETTLE_TOP_DIST.mpr+0.627120023765070)))

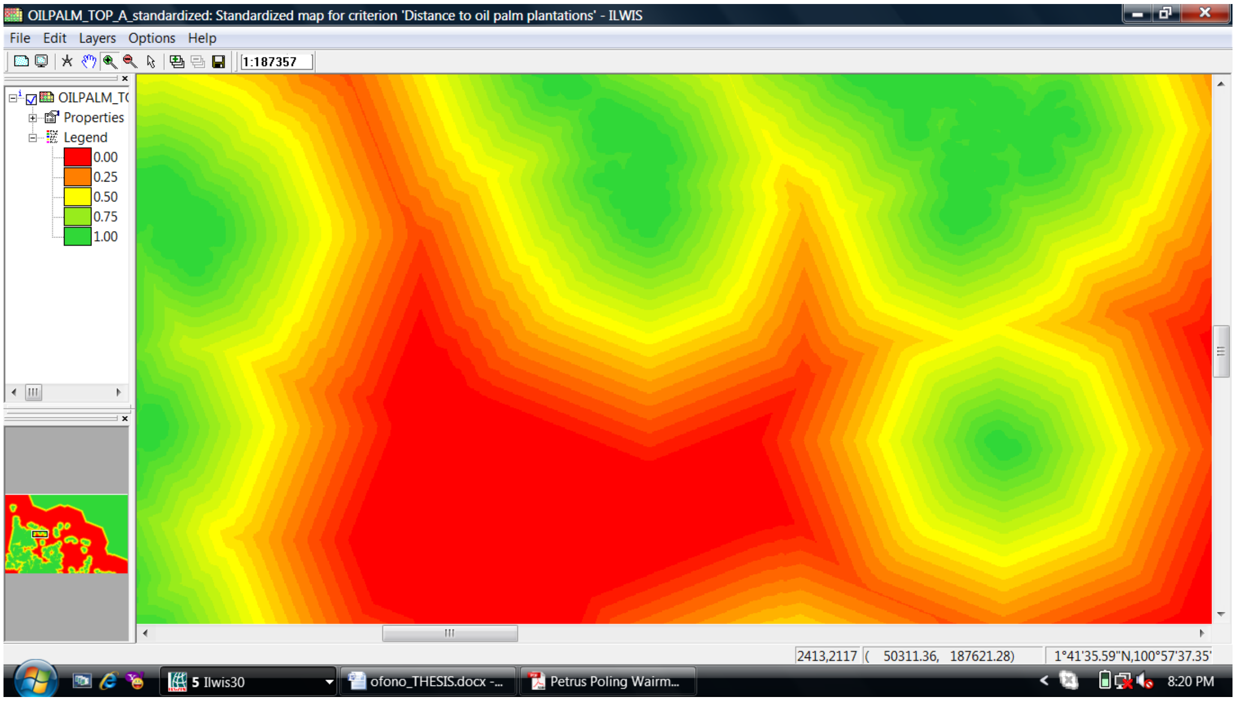
• ROAD_BR_G=iff(ROAD_BR_DIST.mpr>5000,0,min(1,max(0,-0.000000010084345*ROAD_BR_DIST.mpr*ROAD_BR_DIST.mpr-0.000159714752269*ROAD_BR_DIST.mpr+1.000000000000000)))   • ROAD_TOP_G=iff(ROAD_TOP_DIST.mpr>5000,0,min(1,max(0,-0.000000010084345*ROAD_TOP_DIST.mpr*ROAD_TOP_DIST.mpr-0.000159714752269*ROAD_TOP_DIST.mpr+1.000000000000000)))   • ROAD_BL_G=iff(ROAD_BL_DIST.mpr>5000,0,min(1,max(0,-0.000000010084345*ROAD_BL_DIST.mpr*ROAD_BL_DIST.mpr-0.000159714752269*ROAD_BL_DIST.mpr+1.000000000000000)))
• OILPALM_TOP_G=iff(OIL_PALM_TOP_DIST.mpr>10000,0,min(1,max(0,0.000000006447900*OIL_PALM_TOP_DIST.mpr*OIL_PALM_TOP_DIST.mpr-0.000163111687034*OIL_PALM_TOP_DIST.mpr+1.000000000000000)))   • OILPALM_BR_G=iff(OIL_PALM_BR_DIST.mpr>10000,0,min(1,max(0,0.000000006447900*OIL_PALM_BR_DIST.mpr*OIL_PALM_BR_DIST.mpr-0.000163111687034*OIL_PALM_BR_DIST.mpr+1.000000000000000)))   • OILPALM_BL_G=iff(OIL_PALM_BL_DIST.mpr>10000,0,min(1,max(0,0.000000006447900*OIL_PALM_BL_DIST.mpr*OIL_PALM_BL_DIST.mpr-0.000163111687034*OIL_PALM_BL_DIST.mpr+1.000000000000000)))

Appendix 4: Examples of a distance and standardized map

Distance to oil palm concessions' map



Standardised distance to oil palm concessions' map



Appendix 5: Screen shots of criteria trees constructed for different groups

Criteria Tree	
Oil Palm Site Selection -- Direct	Conserv_TOP_ VALUE_NEW_Vision
Not in HCVF -- Std:Min=0.1	HCVF_TOP_DIST
Not in water bodies -- Std:Min=0.1	WATER_TOP_DIST
Not in the road -- Std:Min=100	ROAD_TOP_DIST
Not on Mangroves -- Std:Min=0.1	MANGROVES_TOP_DIST
Not on existing oil palm plantations -- Std:Min=0.1	OIL_PALM_TOP_DIST
Not in protected areas -- Std:Min=50	PARKS_TOP_DIS
Not in Peat/Swamp areas -- Std:Min=0.1	PEAT_TOP_DIST
Not in built up areas -- Std:Min=0.1	SETTLE_TOP_DIST
0.10 Elevation -- Std:Goal(0.000,1.000)	DEM_TOP_C
0.12 Slope steepness -- Std:Attr='Slope_v'	SLOPE_TOP_SL
0.18 Dist.to HCVF -- Std:Maximum	HCVF_TOP_C
0.14 Dist. to water bodies -- Std:Maximum	WATER_TOP_C
0.14 Dist. to swamps and peat land areas -- Std:Maximum	PEAT_TOP_C
0.16 Land use -- Std:Attr='LAND_ALL'	landcover_2007_TOP:LANDCOVER
0.08 Dist. to the main road -- Std:Goal(0.000,1.000)	ROAD_TOP_C
0.06 Distance to markets -- Std:Maximum	MARKET_TOP_C
0.04 Distance to oil palm plantations -- Std:Goal(0.000,1.000)	OILPALM_TOP_C

A screen shot of a criteria tree for the primary perspective: Conservation stakeholders

Criteria Tree	
Oil Palm Site Selection -- Direct	Overall_TOP__new_Vision
Not in HCVF -- Std:Min=0.1	HCVF_TOP_DIST
Not in water bodies -- Std:Min=0.1	WATER_TOP_DIST
Not in the road -- Std:Min=100	ROAD_TOP_DIST
Not on Mangroves -- Std:Min=0.1	MANGROVES_TOP_DIST
Not on existing oil palm plantations -- Std:Min=0.1	OIL_PALM_TOP_DIST
Not in protected areas -- Std:Min=50	PARKS_TOP_DIS
Not in Peat/swamp areas -- Std:Min=0.1	PEAT_TOP_DIST
Not in built up areas -- Std:Min=0.1	SETTLE_TOP_DIST
0.09 Elevation -- Std:Maximum	DEM_TOP_A
0.11 Slope steepness -- Std:Attr='Slope_v'	SLOPE_TOP_SL
0.20 Dist.to HCVF -- Std:Goal(0.000,1.000)	HCVF_TOP_A
0.18 Dist. to water bodies -- Std:Maximum	WATER_TOP_A
0.16 Dist. to swamps and peat land areas -- Std:Maximum	PEAT_TOP_A
0.13 Land use -- Std:Attr='LAND_ALL'	landcover_2007_TOP:LANDCOVER
0.04 Distance to markets -- Std:Goal(0.000,1.000)	MARKET_TOP_A
0.07 Dist. to the main road -- Std:Maximum	ROAD_TOP_A
0.02 Distance to oil palm plantations -- Std:Maximum	OILPALM_TOP_A

A screen shot of a criteria tree for the primary perspective: All stakeholders (over all vision)

Criteria Tree	
Oil Palm Site Selection -- Direct	OILPALM_TOP_NEW_Vision
Not in HCVF -- Std:Min=0.1	HCVF_TOP_DIST
Not in water bodies -- Std:Min=0.1	WATER_TOP_DIST
Not in the road -- Std:Min=100	ROAD_TOP_DIST
Not on Mangroves -- Std:Min=0.1	MANGROVES_TOP_DIST
Not on existing oil palm plantations -- Std:Min=0.1	OIL_PALM_TOP_DIST
Not on burnt -- Std:Min=0.1	BURNT_TOP_DIST
Not in protected areas -- Std:Min=50	PARKS_TOP_DIS
Not in Peat/swamp areas -- Std:Min=0.1	PEAT_TOP_DIST
Not in built up areas -- Std:Min=0.1	SETTLE_TOP_DIST
0.10 Elevation -- Std:Maximum	DEM_TOP_O
0.16 Slope steepness -- Std:Attr='Slope_v'	SLOPE_TOP_SL
0.10 Dist. to water bodies -- Std:Maximum	WATER_TOP_O
0.18 Dist.to HCVF -- Std:Maximum	HCVF_TOP_O
0.12 Dist. to swamps and peat land areas -- Std:Maximum	PEAT_TOP_O
0.14 Land use -- Std:Attr='LAND_ALL'	landcover_2007_TOP:LANDCOVER
0.08 Dist. to the main road -- Std:Maximum	ROAD_TOP_O
0.04 Markets -- Std:Goal(0.000,1.000)	MARKET_TOP_O
0.06 Distance to oil palm plantations -- Std:Maximum	OILPALM_TOP_O

A screen shot of a criteria tree for the primary perspective: Oil palm growers